Army Research Laboratory

Unmanned Aerial System, New System Manning Prediction

by Bruce P. Hunn

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14. ABSTRACT

This study examined historical, laboratory, field, and unmanned aerial system (UAS) model data to develop a manning estimate for a new, long range, Army UAS. System safety and effectiveness, training, contractor operations, and working conditions were evaluated for current UASs, including Hunter, Shadow, Predator, Improved Gnat, and to a lesser degree, Pioneer, Hermes, and Global Hawk. Information was collected from training and operational personnel and included questionnaire data, improved performance research integration (IMPRINT) modeling efforts, mathematical modeling as well as subject matter expert opinions on the issues of manning for current UASs and projections for the new UAS. A review was also made of the system specifications for Shadow, Hunter, and a newly proposed UAS in regard to existing or proposed capabilities that would affect manning levels. Lessons learned were obtained from operationally deployed UAS personnel in order to understand the applied manning levels, which sustained combat operations versus specification levels. Safety as well as accident and incident information was reviewed for fielded systems, and lessons learned that apply to manning levels were discussed and incorporated into the recommendations and conclusions. Conclusions and recommend-dations for the new system are included and cover military manning levels, contractor participation, as well as suggested improvements regarding manning efficiency and UAS operations enhancement. Manning metrics for the new system were derived and baseline and spiral development manning levels were recommended.

15. SUBJECT TERMS

crew workload; flight safety; manpower estimation; modeling; predictive estimation; UAS

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1. Introduction

The unmanned aerial system (UAS) is currently providing military and civilian decision makers with intelligence information from highly mobile locations that can persistently survey the battlefield. In the continuing trend toward more sophisticated and autonomous observation and combatant roles within the battlefield, new UASs are also being proposed and created, and one of the critical questions associated with new UASs is the level of manning[1] that will be required for a proposed UAS. Most proposed UASs will have more capability and flexibility than current UASs, but how many personnel and what type of personnel will be required to operate and maintain those systems? This report is based on a study recently accomplished for the Program Manager of a new Army UAS program and is being rewritten as a technical report in order to communicate some of the approaches taken during that study, which may serve as lessons learned for other future systems studies that involve manning or prediction of future system characteristics.

Planning for accurate manning levels for any future system is problematic since system technology is rapidly evolving, and before the system is actually created, considerable variability and uncertainty are associated, thus making this type of estimate difficult.

It is proposed that in the prediction of manning for a future system, a wide variety of orthogonal approaches should be examined and that each of these approaches be weighted and folded into a summary judgment on manning levels for a new system. Convergence of multiple data sources is proposed as a powerful tool in helping us understand the dynamics of predicting the manning needs (or any needs) of a future system.

2. Methodology

It is proposed that at least three areas of interest and several formal assumptions be evaluated in the determination of how many personnel should support a future UAS. *Each of these should be orthogonal to the others and should converge on a similar system manning conclusion.* Following are the three areas of interest that are suggested for estimating future manning levels for a UAS program, as well as the critical assumptions that need to be made before a final conclusion can be formed. This information is also followed by several critical questions that should be considered in a manning study effort. The focus of this report is on a system-wide manning prediction approach. Individual positions supporting the new UAS are discussed, but the primary emphasis is on overall manning levels rather than on individual positions, military

[1]Manning means how many personnel are needed to support a proposed UAS.

occupational specialty (MOS), or roles within a UAS company; these details are covered in the appendices. Ensuing work is proposed to determine how this company-level manning estimate can be extended to Army-wide manning for any new system.

2.1 Literature Search

A literature search should be conducted on current UAS manning history. This should cover not only Army UASs but other Department of Defense (DoD) or commercial UASs whose role will be similar to the proposed UAS. This literature search should cover the operational requirements document (ORD) and tactical requirements document (TRD) documentation to understand the proposed UAS requirements, as well as current UAS requirements. Particular attention should be made regarding the level of capability that each system has in relation to its manning level. This approach would also collect other services' study data that address manning of current or future UASs.

2.2 Field Interviews

Field interviews should be conducted with subject matter experts (SMEs) who are or recently were experienced UAS operators. Interviews should contain questionnaires that collect data that can be entered into formal, modeling programs as well as help shape the nature of inquiry about how current manning levels have operationally performed (i.e., they should reflect the effectiveness of current UAS manning levels). This is critical since requirements documents may often specify how many personnel are required for a system, but then based on field experience, those systems may or may not be operating effectively at those system specification levels of manning. It is critical to receive feedback from the field in order to determine if the specified manning levels are working effectively. Questions such as "Does the current system require more or fewer personnel than the system specification permits?" should be asked, recorded, tabulated, and analyzed for content and consequences.

2.3 System and Mathematical Models

Modeling future system manning should also rely on the power and flexibility of structured models or mathematical projection. Discrete event modeling systems such as the Improved Performance Research Integration Tool (IMPRINT) can be used to help determine future system manning needs by examining the products or outcomes of varying manning levels, long before the system is actually created. In the same way, mathematical models can predict trends in data, which may be very diagnostic and useful to estimate future events. Regression models have the ability to examine not only current manning trends but to help in predicting trends evident in current systems. While there is always risk in predicting the future, quantitative methods often provide an understanding of numeric trends that may extend into the near term. Several mathematical models that use interpolation and extrapolation designs should be employed to provide a perspective from various, and hopefully orthogonal, points of view.

2.4 Establishing Study Assumptions

Before future trends in UAS manning are predicted, certain assumptions must be made and followed as part of the methodology plan. The following assumptions are offered as suggestions and have been used in previous modeling efforts for a new and near-term Army UAS program (Hunn, 2005):

- The technology used to support this future system will not be radically different than that in current systems, or if changes are anticipated, then compensation in the estimation must be made for their effects.
- Technology changes in a new system are most likely to be evolutionary rather than revolutionary in nature, and if this is not the case, again, compensation must be made in the estimation process. Examples: common assumptions for a new UAS might include the following considerations: the design will primarily be fixed wing, with a propeller or jet engine power plant, and a conventional airframe. Its launch and recovery operations should be similar to the latest technology UAS. Should a significant technological change occur, then the ability to predict manning based on this study's assumptions will be negatively affected.

2.5 Manning Study Questions

Questions associated with the undertaking of a manning study for a new UAS are complex and interrelated. Table 1 outlines some of the areas of concern that might be raised in regard to manning issues. This list is not comprehensive but may serve as a general guideline of areas of interest where UAS manning is being considered and was used as a guideline in a recent U.S. Army UAV manning study (Hunn, 2005).

Table 1. UAS manning study questions.

Questions Associated With UAS System Manning
What are the manning requirements to transport and maintain the system?
What are the workload/vigilance requirements of the UAS pilot and sensor operator?
For how long of a work shift will the ground crew be required to operate?
What are the existing or proposed regulations covering work shift schedules?
Are special physical or cognitive skills required to operate the new system?
What level of training is required for each task?
What current system most accurately represents the proposed system?
What empirical data are available on the current systems to support comparisons?
What methods are best suited to predict the qualities of a future system?
What is the most comparable current system manning level?
What are the surge or wartime manning requirements?
What are the regulations associated with manning, such as MOS classifications needed?
What are the physical or psychological factors that contribute to human UAS control performance?

What method can be used to estimate the manning for a proposed system that best captures the number and type of personnel needed to fulfill all the requirements of this new system? Future

growth potential (spiral development) of the new system should also be considered as a factor to be examined.

An example of one approach is to determine certain minima, for example, is there a minimum of personnel needed in a ground control station (GCS)? If two personnel are typically required to operate the system, are their roles interchangeable or separate? Who can relieve these personnel? What about scheduled breaks? From a simple physiological perspective, it is not reasonable for a Solider to complete a 10-hour shift without eating, drinking, or taking bathroom breaks. This simple fact thus dictates that perhaps an additional person should be available and on immediate call to relieve the GCS operators any time during the mission. They also may provide critical redundancy in case work overload of the primary air vehicle operator (AVO) or mission payload operator (MPO) occurs for any reason.

In determining manning levels, it is also important that flexibility in scheduling be provided, which includes task redundancy, allowance for sickness, temporary duty, or other reasons why personnel may not all be available at the same time. Single point failures in manning can often lead to highly negative situations when mission success is compromised, and during wartime conditions, this is critical. In a similar situation, personnel contributing redundantly may result in a far more efficient system than just having a single person on station. This may be particularly true with the MPO position, when an extra pair of eyes may make the difference between detecting a target and missing a target. This principle has always been in use in the cockpit of larger military and commercial aircraft when other crew members, notably navigators, help scan the sky for other aircraft during the critical take-off and landing time frames. This intermittent duty does not usually affect the overall mission of the navigator but does enhance the safety of the entire mission. In the same way, additional personnel can contribute to overall team efficiency by temporarily ceasing their individual tasks to support the overall mission. There is also evidence that a certain number of personnel may be required to perform certain duties, that is, a minimum team may be required to complete a certain task. For example, if a large piece of equipment is being moved manually, if the object is symmetrical, an even number of personnel is the best approach to manipulate the object so that the lift loads are spread evenly and no individual is over-taxed. In the same way, a team functioning at best efficiency will probably have a certain optimum number of personnel to support that effort. Too few personnel may result in individual work overload, while too many will result in too little effort from each person on the team and thus result in wasted effectiveness. One of the purposes of this study is to find that level where effectiveness is maximized, with the minimum number of personnel.

3. Results

3.1 Current UAS Manning

An example of a current UAS manning is shown in table 2, which shows the historic manning levels of Hunter, Shadow, I-Gnat, and Predator (Office of the Secretary of Defense, 2003b).

Table 2. Manning levels for current UASs.

Personnel	**Hunter (12 hours), six air vehicles (AVs), four GCS)**	**Shadow (3 to 12 hours), three AVs (two GCS)**	**Predator (12 to 40+ Hours (four AVs, one GCS)**	**I-Gnat (12 to 30+ hours) three AVs, one GCS, two portable ground data terminals (PGDTs)**
Personnel	53	22	55	13

Table 2 indicates several significant points regarding crew operations. A comparison of current UASs shows that the Shadow was allocated and operationally used far fewer personnel than either the Hunter or the Predator.

The following discussion only focuses on the personnel who are required to support the mission overall; they do not consider additional duties that might occur during a deployment or that might occur during wartime conditions (physical training, kitchen patrol, guard duty, etc.). With Army regulations (Department of the Army, 2004) requiring a maximum flight duty day of 10 hours and an overall duty day of 14 hours maximum, personnel assigned to Hunter or Shadow aircraft can often expect 4 additional duty hours after their normal, maximum flight shift (Hunn, 2005).

3.2 UAS Capability

One of the prime criteria that affect manning is the level of capability required to support each UAS mission. The use of current UASs involves inherent capabilities, and a comparison of those capabilities and their associated manning levels is presented in appendix A. For the purposes of discussion, the new system being evaluated will have considerably more capabilities than existing systems.

3.3 SME Surveys and Modeling Tools

Participants involved with evaluating manning levels should include a wide range of experience levels. For example, in the understanding of manning for a future system, it is suggested that information be collected from experienced (SME) and inexperienced operators. Questionnaires about each of their systems can be patterned after the Army UAS operating procedures manual (Department of the Army, 2000; 2002). In a recent IMPRINT Shadow UAS study, approximately 80 questions about normal procedures and approximately 25 questions about emergency procedures were answered by a variety of participants (see appendix B).

Areas of information covered task times required for normal and emergency operations, the number of personnel required to complete the tasks, as well as estimates of the frequency of occurrence of emergency tasks. Workload for each task was assessed qualitatively with a rating scheme developed by McCracken and Aldrich (U.S. Army Research Laboratory, 2003b). That approach relied on rating workload on four scales: visual, auditory, cognitive, and psychomotor (U.S. Army Research Laboratory, 2003b). These workload attribute scales are consistent with the multiple resource theories of Christopher Wickens (Procter & Van Zandt, 1994) and have been used in ARL IMPRINT modeling efforts for many years. This information can be used to baseline the manning requirements for a variety of current systems and to help define time, workload, and task-sharing issues of current UAS crews. Establishing this historical baseline of information allows trend lines to be developed and thus provides a method of projecting current trends into the near-term future.

Field personnel, particularly personnel returning to the states from recent war-time deployments, are important sources of fresh information and should be actively sought for a realistic study outcome. They are best acquainted with how well manning levels actually work in field conditions, and they have information that should be seriously considered when one is extrapolating or predicting future manning needs.

3.4 Critical External Factors Associated With UAS Manning

Numerous factors associated with UAS manning should be considered, and some may heavily influence the outcome of a manning study. In particular, the following factors will contribute or even control any theoretical conclusions drawn because they represent existing command or management criteria that can override any study's recommendations. Some serve as mandatory guidelines and must be considered, while others reflect best engineering or human factors practices and should also be considered.

3.4.1 Army Regulations

Any study of manning requirements for UASs must consider existing Army UAS regulations that pertain to manning. Currently, AR 95-23 (Department of the Army, 2004) provides management, operations, safety, training, flight procedures and rules, safety of flight messages and aviation safety action messages as well as weight and balance guidance for UASs. Specifically, for the purposes of a manning study, UAS crew member endurance considerations are important. Additional guidance for UAS safety operations can be obtained from Training Circular (TC) 1-210, Chapter 5, Risk Management (Department of the Army, 1995). When one is conducting a manning study, these background regulations may or may not conflict with the actual needs of proposed systems.

A review of AR 95-23 (Department of the Army, 2004) reveals several elements that will affect the manning of future UASs, specifically flight crew endurance requirements. Reproduced in

table 3 is table 3-1 from AR 95-23, which covers crew endurance requirements; items in *underlined italics* are current input to that regulation made by the 305th MI BN UAS training school personnel.

The recommendations listed in table 3 provide maximum flight time recommendations for AVOs; however, based on a wide variety of human vigilance research as well as reported practice in Army operational units, the times at which UAS operators are actually on station are considerably less. In practice, some operational Army units in war-time missions tend to rotate their flight personnel at intervals more frequently, commonly approaching 4-hour increments (senior non-commissioned officer [SNCO], 1-14th Cavalry, personal communication, August 20, 2004). At the other extreme, another study's research (Hunn, 2005) uncovered a situation reported by an SNCO in which a single Shadow crew operated for a 96-hour period during an operational engagement.

Table 3. Table 3-1, crew endurance guide, AR 95-23 (Department of the Army, 2004).

Time Period (Days)[1]	Maximum Duty Period (Hours)	Maximum Flight Time (Hours)	Environment Relative Factors
1 to 7	*14 (14 hours to 16 hours is currently being recommended as a change in this regulation)*	*10 (8 hours is currently being recommended as a change in this regulation)*	*Day 1.0*
7	*84*	*48*	*Night 1.4*
14	*160*	*88*	*Mission-Oriented Protective Posture IV (MOPP-4) 2.0 (Changing 2.0 relative factor to 3.1 for MOPP-4 is a currently recommended change in this regulation)*
30	*320*	*90 Peacetime* *140 Mobilization*	

[1]UAV crew members should be afforded quality, uninterrupted sleep to prevent fatigue, unclear thinking, and poor decision making that could result in unsafe UAV operations.
a. Commanders will design a crew endurance program tailored to their unit mission and include it in their standard operating procedures. Table 3.1 is provided as a guide for scheduling AVO duty periods.
b. Crew endurance is an integral part of the overall risk management program. It is used to control risks attributable to sleep deprivation or fatigue and to prescribe thresholds to trigger command decisions as to whether to accept those risks.
c. Commanders should consider the advice of flight surgeons and aviation safety personnel in designing their crew endurance programs.

3.4.2 Operational Crew Workload Considerations

It is proposed that operator fatigue is induced not only by over-activity but also by imbalanced activity (workload highs and lows) or even inactivity. For example, consider the following observations relayed by operational Army UAS crews.

3.4.3 AVOs

For AVOs controlling the aircraft, workload is at a peak during mission planning, take-off and landing, crew transfer, and with unplanned mission route changes (Williams, 2004), this was

confirmed by IMPRINT modeling as demonstrated later in this report. It is during these times that the UAS pilot (AVO) must maintain his highest vigilance level and must operate, integrate, or manage the maximum number of systems, as well as provide oversight in case of an emergency. Even with automated take-off and landing, if a problem occurs, the risks for an AV mishap are much higher than for a phase of flight en route. If a manual override or safety procedure is needed, it must occur in very tight time constraints (Hunn, 2004). En route changes also require interaction with a large number of control and display interfaces, as well as communication tasking to a wide array of customers (Hunn, 2004).

3.4.4 MPOs

The MPO (in contrast to the AVO) may have reduced workload at take-off and landing, but once en route, his workload may rise and fall unpredictably with planned target load and targets of opportunity. Vigilance consequently must be maintained for a long period of time, often at high levels; otherwise, high-value targets of opportunity may be lost. MPO en route observations through optical or infrared sensors are common, even when targets of opportunity are not expressly part of the mission. To ignore the importance of en route observation is to ignore one of the great capabilities of the UAS, that is, flexibility in acquiring *ad hoc* targets (Hunn, 2004).

3.4.5 Maintenance Personnel

Maintenance personnel often have uniform workload levels when accomplishing on-vehicle or bench-type routine maintenance; however, poor supply support may necessitate *ad hoc* repair tasks, which require remove and replace “cannibalization”. Such situations require quick thinking and an understanding of the consequences that the temporary shuffling of repair parts has on the overall unit’s mission reliability. Also, the nature of maintenance includes unforeseen or unpredictable breakage of parts or system failures, which often must be compensated for without advanced planning. Battle damage repair is an example of this, where unforeseen damage is inflicted by transit, enemy engagement, or unanticipated climatic extremes. Engine foreign object damage (FOD), exposure to sand storms, snow, or heavy rain are classic examples of environmental maintenance challenges that may occur without warning.

3.4.6 Manning Levels and Safety

A critical consideration in assessing manning for a new system is the interaction of manning levels with safety levels. Understanding the relationship of manning level to human factors-related accidents is a critical area and one that addresses the overall system effectiveness of any manning level selected. One possible approach to assessing this issue is by making relative comparisons of the human factors-related accidents of current UASs in relation to their manning levels. This approach largely negates differences between UASs that are technology or mechanically different, that is, it eliminates those effects and focuses more pointedly on incidents or accidents that are directly related to human error. It is recognized that the

technology level of all UASs will differ by platform, and that for example, a large UAS such as the Global Hawk will have a technological lead over a small UAS such as the Shadow. In terms of maintenance, sustainable flight hours, or other mechanical metrics, it is very likely that the Global Hawk will be able to fly farther, faster, higher, and longer than the Shadow. By focusing only on the elements of accident and incident relating only to direct human error, the issue of human effects on manning and vice versa can be isolated and compared across UASs. The assumption made is that error rates thus isolated allow greater comparability than if those error rates and manning levels are unduly influenced by extraneous confounding variables associated with each system's technology level. This, of course, does not preclude the possibility that the technology may directly contribute to accident and error rates via means such as poor interface design; however, it does reduce some variability by eliminating the comparison of error rates associated with UAS mechanical systems such as power plants, airframes, and aeronautical systems that are remote from the operator's direct involvement or manipulation.

Some examples of UAS operational criteria and system features are discussed next to provide a perspective on the use of current UAS data in predicting future systems manning.

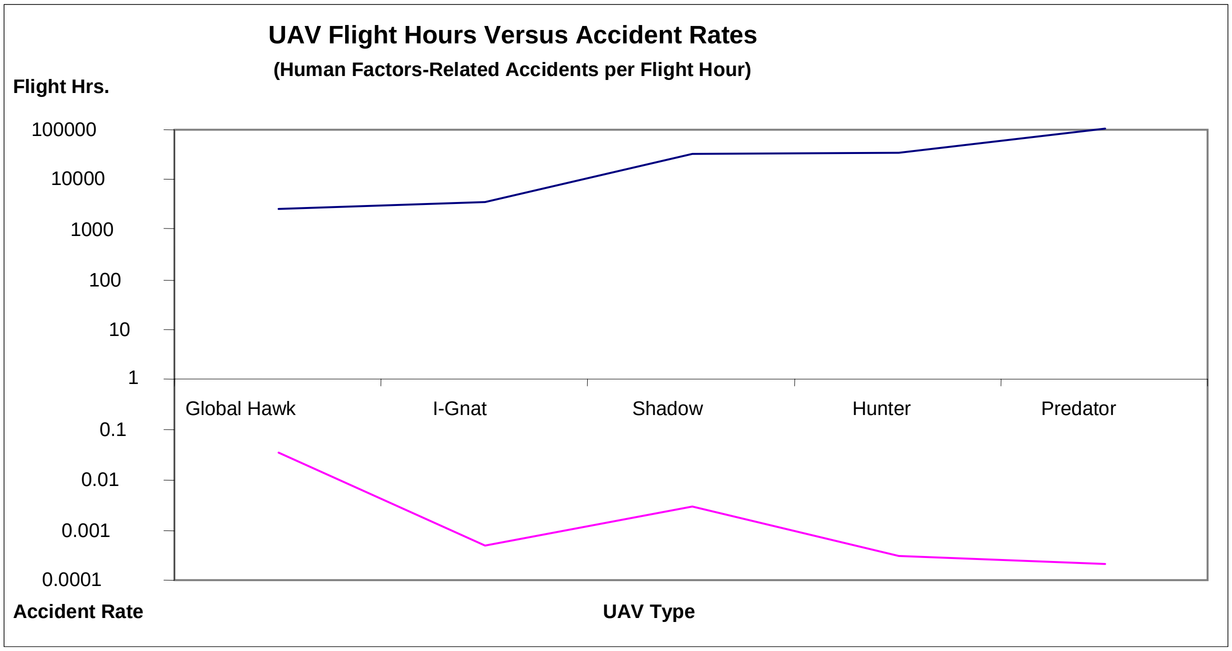
Recently, the Shadow UASs passed the 30,000-flight-hour marker, and the Hunter series also passed the 30,000-hour mark; thus, there is a reasonable amount of data upon which to assess the system needs versus their current manning levels. This milestone in terms of flight hours also allows valid comparisons of systems that have equivalent flight time totals. This comparability in flight hours also translates to the overall likelihood of similar crew familiarity and training equivalency within the realm of the Army UASs.

The Predator with a crew of about 45 to 55 personnel per squadron continues to support U.S. Air Force, Navy, and Coast Guard needs, as well as a host of other country's needs. The U.S. Border Patrol Hermes 450 UAS is currently increasing its operations tempo and is accomplishing that task with a crew of seven (three in the GCS) and four supporting the rest of the flying operations. Extrapolating the Hermes crew size to company strength, we can see that a crew of 28 to 35 (four to five UASs times seven personnel) would be needed to support four to five Hermes UASs. It is also worthy to note that the use of Hermes for U.S. Border Patrol and Homeland Security domestic operations is developmental, and there are very few flight hours available for study. Another very important point to consider is that those agencies do not currently have sustained 24-hour-a-day operations accomplished during combat conditions.

3.4.6.1 UAS (Human Factors) Accident and Incident Rates

Since mention has been made regarding manning levels and safety, figure 1 shows the relationship of human factors-related accident and incident levels as they compare to the number of flight hours flown. This metric allows comparisons to be made, independent of the technology of the individual UAS and independent of any complicating factors that may be attributable to mechanical reliability of those UASs. For the purposes of this report, one significant assumption

being made is that the overall rate of human factors-related accidents in proportion to mechanical accidents is assumed to be at a 50% ratio. This is a modeling simplification that provides rough estimates of error rates. For specific system-by-system error rate classification, it is strongly suggested that a taxonomy of errors be used to describe and detail error types. Such a taxonometric approach is detailed in Tvaryanas, Thompson, and Constable (2005). However, the range for current UAS human error to all other errors is also typically in the 30% to 60% range—thus the simplification of 50% for purposes of illustration.



Note: Figure based on approximate 50% human error versus 50% mechanical error ratio assumption (not all UASs have this same error proportion (see Tvaryanas et al., 2005). The Shadow and Hunter accidents and incidents actually have approximately this same proportion of human versus mechanical causes, while other UASs vary to a greater extent; however, for modeling, a 50% ratio was assumed.
The overall accident and incident rates for all causes for the above UASs are approximately twice the values in this figure (50% x 2 = 100%); therefore, the pattern or relationship of flying hours to accident rate would still stay approximately the same, but the magnitude of the accident rate trend line would shift vertically.
Flight data statistics compiled from Program Manager Offices for each UAS (MAJ Stewart, Air Combat Command, personal communication, January 2005; Office of the Secretary of Defense, 2003a; Bone & Bolkcom, 2003).
An accident for this modeling effort is defined as any event resulting in injury or damage, and includes Class I, II, and III levels as described by military aviation standards.

Figure 1. UAS flight hours versus accident rates.

In order to make valid comparisons of accidents in relation to manning, one must consider the total number of hours the UAS has completed. This is important because accident statistics are often created on the basis of arbitrary levels of flight time, customarily 100,000 flight hours. The problem with this approach is that rates per 100,000 hours are only valid if the UAS in question has flown at least 100,000 hours. In the case of many or this report's UASs, the total hours that have been flown are far fewer than 100,000.

Only the Predator has exceeded 100,000 hours as of the writing of this report, while other UASs may have significantly fewer hours. Figure 1 shows the human factors-related accident rates per the actual number of flight hours flown to date. These data include all flight hours including developmental test time. The information in figure 1 was presented on a logarithmic scale because of the comparison range. Some of the UASs shown have close to 100,000 hours (Predator) versus only 2,500 hours for the Global Hawk. The relationship of hours to accident rate is still apparent as an inverse correlation, that is, as hours go higher the accident rate goes lower. What figure 1 reveals is that independent of the technology level of the platform (e.g., Shadow versus Global Hawk), across all UASs, the greater the number of hours on the UAS platform, the lower the accident rate.

3.4.6.2 UAS System Maturity and Accident Rates

As individual UASs become more mature, the accident rates per individual UAS will drop. As shown in figure 1, there is a very significant drop in human factors-related accidents, but there should also be a corresponding drop in mechanical accidents as those systems are refined and improved. However, since this is a manning report, only the human factors issues associated with manning safety are examined. Again, the point to be made is that statistics reflecting accident rates must relate to a determined cause (such as human error) or if they relate to an accident rate overall, they must have comparable values (equal flight times) with which to compare, and thus predict, a stable overall accident rate. An additional study would still be needed to determine what the stabilized, plateau value would be for any given UAS platform once it reaches a mature system state. Figure 2 shows the accident rates per flight hour for the Pioneer UAS and demonstrates for an individual UAS how rates can drop over time. The first 12,224 hours shown indicate a period of approximately 9 years in 1-year increments.

As manning increases, accidents decrease; this is one way to look at figure 3. The correlation is strong for this effect where $r = -.96$ and upon observation of the curves, it appears that there may also be an effect at about 53 to 55 personnel, where after that level of manning, accident rates drop significantly.

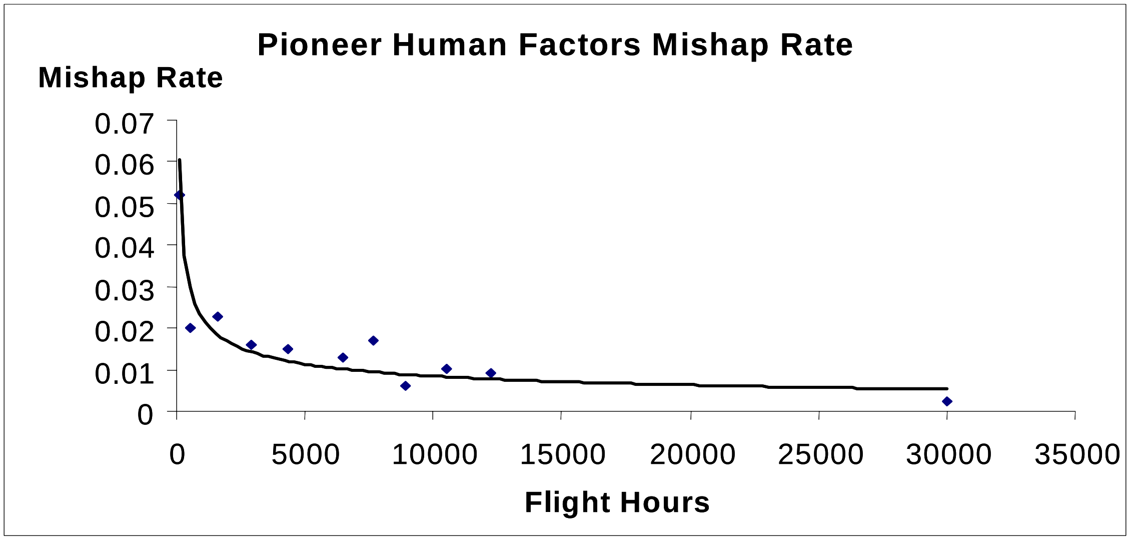
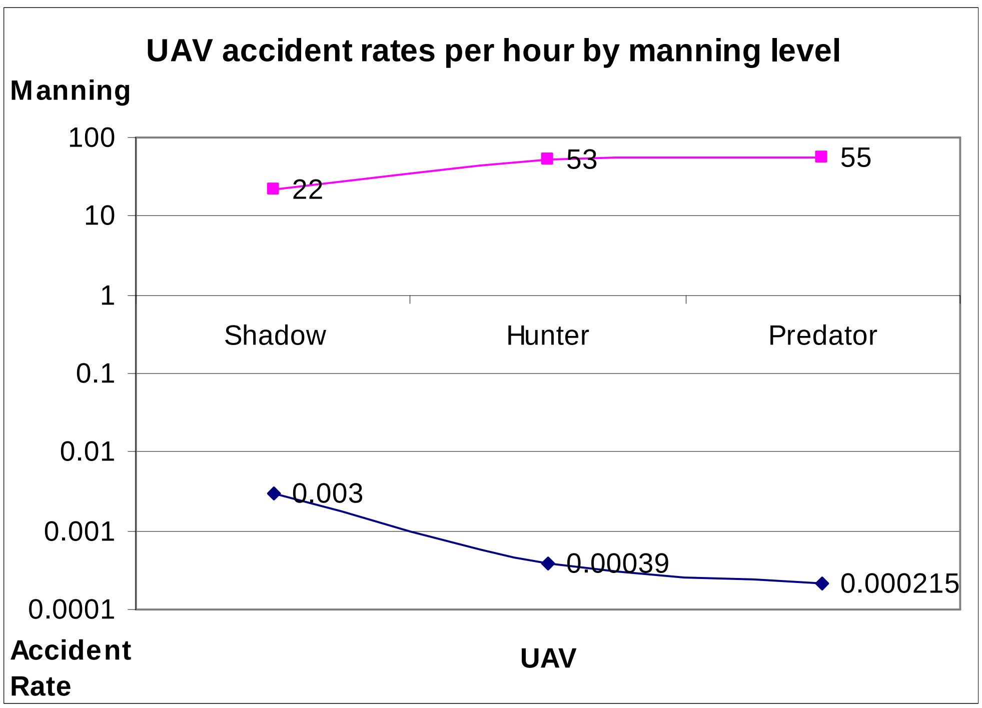


Figure 2. Pioneer human factors mishap rate (1986 through 1995). (Mishaps include all types of accidents.)



Note: Manning based on 24-hour operations

Figure 3. UAS accident rates by manning level.

Two conclusions can be made concerning figure 3: (a) as flight hours increase, experience is gained on any UAS, and (b) there is a certain minimum team value for manning levels, that is to say, the operation may not meet a reasonable level of safety unless there are a minimum number of players involved. Based on the data in figure 3, when the number of personnel equals or exceeds 53 per company, this appears to stabilize or decrease the accident rate.

3.4.6.3 The Impact of New Technology

A final point on manning and safety concerns the ability of a crew to operate with new equipment and back-up personnel. For example, the I-Gnat system is currently being manning with 11 contractor personnel including one site leader, three pilots, two MPOs, three mechanics, and two avionics techs (Dissault, General Atomics, personal communication, January 2005). However, this same UAS when outfitted with a new synthetic aperture radar (SAR) requires two more people, thus pushing manning to a total of 13 personnel. This new capability, once fielded and coupled with a formal training program, may be absorbed by the current MPOs as part of their assigned training and duty.

3.4.6.4 Accident Rates and Manning Levels

Figure 3 demonstrates the rates of accidents as they are compared to the number of personnel assigned to a single UAS battle group. Figure 3 shows a clear monotonic relationship between the overall manning and the accident rate, and it also shows a noticeable trend when manning levels go below a set value per system. As mentioned previously, there are other factors to be considered in this type of analysis; however, based solely on manning alone, there appears to be a clear trend where manning reaches a plateau level of 53 or more personnel; then the incident/accident rate falls dramatically. In comparison, UASs, which have fewer than 53 personnel per aircraft, have dramatically higher accident and incident rates. Figure 3 information, when placed in a correlation analysis, resulted in a correlation coefficient of (r -.946) which indicates a very high negative correlation of manning versus accident rate. This test result means that as manning increases, accident rates decrease.

3.4.6.5 Shadow and Hunter Accident and Incident Rates

Hunter and Shadow represent the most recent large-scale UASs used by the Army and therefore can provide some of the best data upon which to develop historical baselines and predictions for future Army UASs.

Both Shadow and Hunter have similar accident or incident ***rates*** related to human causes, that is, of the recorded accidents to date (September 22, 2004), 48.9% of the Shadow's accidents have been attributed primarily to human factors reasons, while 48.4% of Hunter's accidents can be attributed to human causal factors (305th MI Safety Office, personal communication, Northrop-Grumman, Hunter Safety Report, May 10, 2004). The data from the Northrop-Grumman report were subjected to a categorical analysis by the author of the present report to determine the percentages listed.

3.4.6.6 Potential Accident Causal Variables

Although there is a vast array of possible variables that could lead to in-flight accidents and incidents, there is also a theory that the UAS Reynolds number can be correlated with accident

rates (Office of the Secretary of Defense [OSD], 2003a). This theory states that flight control stability (often a human-controlled factor in UASs) can be affected by the UAS that has a low Reynolds number. The Reynolds number for any aircraft represents the ratio of the aircraft's inertia to the viscosity of the air through which it is moving. This provides a useful scaling term for comparison of aircraft of different sizes and can be used as an index to the controllability of that aircraft in flight. In the OSD report, it was observed that a low Reynolds number is associated with many UASs, particularly the smaller UASs, and the UASs with the lower Reynolds number have greater accident rates.

To provide a statistical evaluation of the Reynolds number UAS controllability concept, a correlation test was performed on Shadow, Pioneer, Hunter, I-Gnat, and Predator weight and air speed data in relation to accident rates. Although the Reynolds number for each of these UASs was not known (the calculation involves air density, speed, wing cord length, and viscosity of the air), the UASs' weight and speed ranges are known, and the variables of weight as well as air speed correlated well to accident rates, with a result of an r of -.89 for weight and an r of -.826 for air speed. What these results indicate is that as weight and air speed of the UAS increase, accident rates decrease (in terms of correlation). Although this does not imply a causal link to their individual Reynolds number, it does support a possible hypothesis in that direction.

Another point to be made about figure 3 is that Predator still has a much lower accident rate than Hunter even though they have about the same number of personnel. The difference may be partially because Predator has 55 personnel supporting one UAS mission, while Hunter is supporting two or three missions with 55 personnel. There are also mission length time differences and greater or fewer numbers of take-offs and landings, as well as significant differences in training levels for both UASs.

3.4.6.7 Vigilance Loss Laboratory Findings in Relation to UAS Operations

Any manning study must consider the work demands of the job before a manpower estimate can be generated. An estimate made without consideration of the human workload level for all the crew assigned to a UAS places considerable risk on that prediction's outcome. It is not sufficient to merely state that a certain number of bodies are required; their level of workload must also be considered in any recommendation. One of the greatest determiners of workload is the level of vigilance, which must be maintained over time (Wellbrink & Buss, 2004). Human fatigue is also an element of vigilance and is discussed in this and other sections.

We previously mentioned operational crews rotating out of station at intervals of 4 hours or less because of perceived loss of attention (vigilance loss) or workload-induced fatigue (Horowitz, Cade, Wolfe, & Czeisler, 2003). Typically, workload is commonly only considered in the case of work overload; however, human performance can be just as ineffective during conditions of under-load.

Not only has workload under-load been observed in the Global Hawk UAS (Hunn, personal observation, 2001) and in U.S. Navy Sonar operators (E Company, 305th MI Safety Officer, personal communication, August 2004), but there is a large body of literature that indicates that vigilance loss may occur within a much shorter time frame than 4 hours (which is a common rotation time limit).

A quick comparison of task duties indicates that the MPO probably requires the highest level of vigilance over time when s/he is scanning for targets. The AVO is next in the need for vigilance in terms of safely and effectively operating the aircraft, particularly when the aircraft is under manual control. In both duty stations in Army UASs, there is some overlapping of duties, particularly when the AVO is monitoring target imagery. The AVO often observes the same screen as the MPO and thus there is redundancy in their ability to observe and detect targets. This redundancy is a positive benefit as long as it does not interfere with the AVOs primary duties (Hunn, 2004).

Other personnel associated with the UAS have tasks that require less sustained vigilance and involve more diverse and physically active tasking. For example, engine mechanics and electronics maintenance personnel have diverse duties that typically do not involve maintaining constant vigilance levels over sustained periods of time. Thus, in terms of work station rotation, they can sustain operations for longer periods of time without the risk of incurring errors based only on a vigilance loss. A comparison of UAS crew tasks might show that for example, an engine mechanic has to step through an assembly checklist in order to maintain the AV; however, that task is highly structured (step by step) and thus has less ambiguity than searching for a concealed missile launcher in a forest (typical MPO task). It also does not require that individual to maintain a constant level of vigilance at the same level as an MPO operator who must maintain constant attention on a screen as new imagery flows by at a varying rates (based on air speed and sensor resolution level).

Other crew members such as the Warrant Officer, Platoon Sergeant, and Platoon Lieutenant have administrative duties that are quite diverse, usually involving a higher level of physical activity than an MPO or AVO: walking, observing, and directing operations and coordinating communication. These activities are typically not repetitious as they are for scanning an image, nor are they highly structured as in following a checklist (AVO, MPO, engine mechanic, or electronics maintainer). It is because of this diversity, both physical and mental, that vigilance does not play as critical a role for their jobs as it would for the MPO or AVO. This is not to imply that each of those crew members does not need to maintain a sense of situational awareness of the battlefield; it is just that the change in their environment provides much less in the way of a vigilance challenge than does the observation of a video screen for rare events, such as an MPO detecting concealed targets.

As a general rule, humans perform poorly at sustained vigilance tasks, particularly if these tasks are designed around monitoring for rare events. In terms of laboratory vigilance studies, there

have been numerous studies that compare the tasks of the MPO and AVO in terms of vigilance. These studies are summarized and briefly paraphrased in appendix B in terms of how they could relate to UAS operators (particularly the MPO and AVO).

3.4.6.8 UAS Air Crew Performance Related to Vigilance Loss

A good case can also be made that manning levels in the Shadow UAS are less than desirable, based strictly on human-related accident and incident rates; however, another important element for any UAS is the effect of vigilance loss as it relates to accidents, incidents, and poor performance. This may result in more subtle mission failures and a general loss of efficiency. An example of this would be loss of vigilance in the MPO with extended term missions. A loss of vigilance is difficult to detect because a missed target remains missed, and thus there is little against which to measure the MPO’s effectiveness.

It is suggested that a detailed mission simulation experiment could assess the impact of vigilance loss on detection and identification of targets and would be able to quantify the mission impact of such a vigilance loss. A simulation also could assess the loss of mission effectiveness without compromising a real mission’s success. It is interesting to note that submarine sonar personnel and USAF Global Hawk UAS air crew are both rotated at their station at 4-hour intervals or less (Fort Huachuca UAS Safety Office, personal communication, August 2004, and Hunn, personal experience regarding the Global Hawk UAS Program). The reason that both of these dissimilar jobs require short work rotations is not overload but under-load, which may result in loss of vigilance and missed targets.

Targets by definition appear infrequently, that is, there is far more surface area to scan than there are targets to find. In addition, targets are rarely obvious because of camouflage or concealment obscuring their perception. While not well quantifiable, non-target imagery in terms of pixels presented to the MPO observer (background scenery) outnumbers targets by factors of hundreds or thousands to one; therefore, detecting targets is not an easy procedure, even given ideal conditions. Since targets are not easy to detect, they will challenge any operator’s level of awareness but particularly if s/he is fatigued or inattentive after many hours of viewing repetitious scenery.

The chances of missing a rare event (the target) are increased as flight time and fatigue are increased (Air Force Research Laboratory, 2004). This is the challenge of vigilance or remaining aware when target presentation is infrequent. In the case of the AVO, maintaining total awareness of all the aircraft systems, particularly when they are semi-automated, is more of a monitoring chore than an interactive process, such as would occur in a manned aircraft environment. It was also reported by I-14th Cavalry personnel (August 2004) that some Shadow field units are beginning to rotate their crews at intervals of less than 4 hours to compensate for vigilance loss (further information about vigilance is given in appendix C).

3.4.6.9 Air Crew Physiological Issues

An additional consideration for any UAS AVO or MPO is that physical activity is greatly reduced in the GCS, as opposed to piloting in a manned aircraft. The physiological demands of a manned aircraft including G forces, vibration, noise, requirements for physical force application (pedals, sticks, yolks, collectives, throttles, etc.), plus the physiological demands of head and upper body movement from visual scanning, and the very real adrenalin flow from anticipation of any contact with the enemy. All these factors combine to increase vigilance levels above the static level in a GCS. In manned aircraft, these physical demands result in a generally higher level of physiological activity, which in turn increases the air crew's physiological arousal level and enhances their physical vigilance capability. This is a well-known and accepted concept associated with understanding vigilance and performance levels in humans. The physiological challenge in the UAS is not from physiological overload as much as it is from physiological under-load. Several simulation studies have explored the effects of fatigue on UAV crew performance (Walters, French, & Barnes, 2000; Walters, Huber, French, & Barnes, 2002).

Additional physiological demands may result from working conditions, which on recent deployments involve exposure to temperatures in the 140 °F range. While the GCSs are cooled, they often are not cooled to an optimal level of comfort of 68° to 72 °F (non-commissioned officer [NCO], 1-14th Cavalry, personal communication, August 2004). The limitations of heat exposure are also well documented and have impacts on personnel physical and mental performance, particularly over extended time periods.

Air crew endurance recommendations are derived from regulations pertaining to manned aircraft (such as AR 95-1 [Department of the Army, 1997]) and are then transferred to UAS air crew guidance documents, AR 95-23, for example (Department of the Army, 2004). When endurance requirement recommendations are transferred, there is a risk in assuming that the duties for manned and unmanned systems are similar when they are not.

3.5 Current UAS Manning Information

The following data were collected to further explain some of the manning dynamics associated with current UASs from several services.

3.5.1 Experience Levels

Commercial contract UAS crews typically include a wide variety of personnel (in terms of experience) ranging from former U.S. military personnel who have already had formal DoD training and may have considerable UAS or military experience in operational settings to commercial UAS crews who may have had only several weeks of training. (Additional information related to training is contained in appendix D.)

3.5.2 Duty Day

The USAF mandates a 6-hour UAS duty day, and more importantly, it tries to maintain a 2- to 4-hour on-station rotation rate for crews. Lessons learned from USAF airborne warning and control operators and radar operators indicated that after 2 hours of operation, vigilance was decreased to the point of increased error; thus, a more frequent rotation of crews to keep them "fresh" was implemented. This is particularly an important factor to consider for MPOs or sensor operators.

3.5.3 Predator Operational Manning Information

Additional information about Predator manning acquired from the USAF Research Lab (AFRL) was acquired from the 15RS (15th Reconnaissance Squadron) Predator squadron. War-time operations in excess of 1000 days on a 24-7[1] basis were recently completed, and many personnel problems associated with that surge effort were reported (Miller & Dart, 2004). Manning was based on nominal 45 to 55 personnel per squadron and the use of a highly variable rotating shift basis. This level of effort negatively affected morale and accident/incident rates. As a result of this less than optimal work schedule, a consultation manning study was directed toward the AFRL's Human Performance Division, Fatigue Countermeasures Branch. They were directed to determine how the shortfalls experienced during this engagement could be compensated through the adoption of a new work schedule. That study's conclusions indicate that while meeting most of the requirements for that war-time surge engagement, the schedule and manning levels were far from optimal (Miller & Dart, 2004).

The schedule used during this surge was a 15-hour day composed of a 12-hour shift with a 3-hour differential, and a 9-hour night shift. This was segregated into days: three 5-hour blocks, with 2.5-hour sub blocks, the MC operating on a 5-hour block, and for nights, three 3-hour blocks. Specifics of the work degradations that occurred during this deployment are not currently available; however, the lessons learned from this situation (which is still unfolding) is that better use of time, in terms of scheduling, is required and that manning levels should be increased above the current allocated levels to avoid this situation in the future. Since this situation is ongoing and of a sensitive nature, the only results from this study which can be reported are the recommendations regarding scheduling of personnel. This study (Mc & Dart, 2004), which was completed on November 18, 2004, has had its primary recommendations reproduced in appendix E.

3.5.4 Summary of 2004 AFRL Predator Manning Study

Of particular note to the study's recommendations, other than a new fixed time shift schedule, is the recommendation to increase Predator manning to 124% of then current manning levels. This value, a 24% increase in manning will be an important contributor to predicting manning for the next generation UAS. As discussed previously, proper shift scheduling and an effective number

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[1] 24-7 means 24 hours a day, seven days a week

of personnel are important to adequately staff this type of UAS operation. A third element of that study was the recommendation to only require 6 flying hours per shift, with the balance directed to additional duties as assigned. The 6-hour flying shift reduction from the original 8- to 10-hour shift is very much in accordance with all the available literature associated with human vigilance studies.

3.6 Modeling a UAS Manning Level With IMPRINT

When one is predicting future manning levels for a new UAS, a simulation model can be created via IMPRINT V 7.12. This ARL modeling system uses data collected from various UAS SMEs and considers workload levels, number of personnel assigned to a task, the conditions under which personnel work, the types of tasks they perform, and then calculates predictive manning factors. The model uses these data and runs a Monte Carlo simulation (statistical model), which looks at task performance as if it were repeated many times, thus predicting the variability, which might occur in a real-life scenario (ARL, 2003a). This modeling approach has been proved in the past to be able to predict manning and workload levels for a variety of systems, including Hunter and Shadow tactical UASs.

The IMPRINT model created considers each air crew member's duties, the quality of the work being performed, effects of emergencies on tasks, manning levels, overlapping duties, and fatigue factors. It is particularly useful if task details for the new system are known or can be estimated. The more detail known about the proposed system, the better it is for the fidelity of the model created. The model can also allow prospective concepts to be tested at low cost. In addition, extraneous factors such as the use of MOPP gear or extended flight time fatigue effects can be modeled. However, the limitation to a predictive model such as this is that there is no new UAS for which data can be collected. In this case, another interpretive approach is to use a current UAS and interpret its results to a new system by similarity.

In a recent study, an IMPRINT model was created that was derived from a second generation Shadow 200 model. The first generation Shadow 200 model was created in 1999-2000 by ARL to support Shadow program development and to develop manning estimates under constraints of varying crew size and under potential changes in crew fatigue. This model was revised with a considerable amount of field data collected from Shadow field personnel by Hunn (2004). For the revised effort, questionnaires were sent to 16 members of the I-14th Brigade who had recently returned from an operational deployment in Iraq for UAS refresher training at Fort Huachuca. The questionnaires consisted of 105 questions requesting information about each major task drawn from the Shadow's operating manual (Department of the Army, 2002) and covered all aspects of Shadow operation including emergency procedures.

3.6.1 UAS Workload Estimates

Figures 4 and 5 show the results of an IMPRINT model of workload based on surrogate (Shadow UAS) data. These data were collected from recently deployed Shadow UAS troops returning from Iraq. Although figures 4 and 5 show the results of a Shadow mission of about 2.5 hours, they are also representative of a typical UAS mission. Although it is very difficult to predict workload levels for a concept system, it is believed that these Shadow data can be used as a baseline for estimating the range and pattern of workload that may be associated with a new UAS. In terms of extending these results to a new UAS, it should be considered that the overall pattern of workload may remain (based on a similar mission profile) but that the levels of workload might shift up or down, depending on system characteristics. The analogy is that given two UASs performing the same mission, the overall pattern of workload would probably be the same based on their tasking, while one system or the other would be easier or more difficult to operate overall, thus changing the amplitude of the workload pattern rather than its shape.

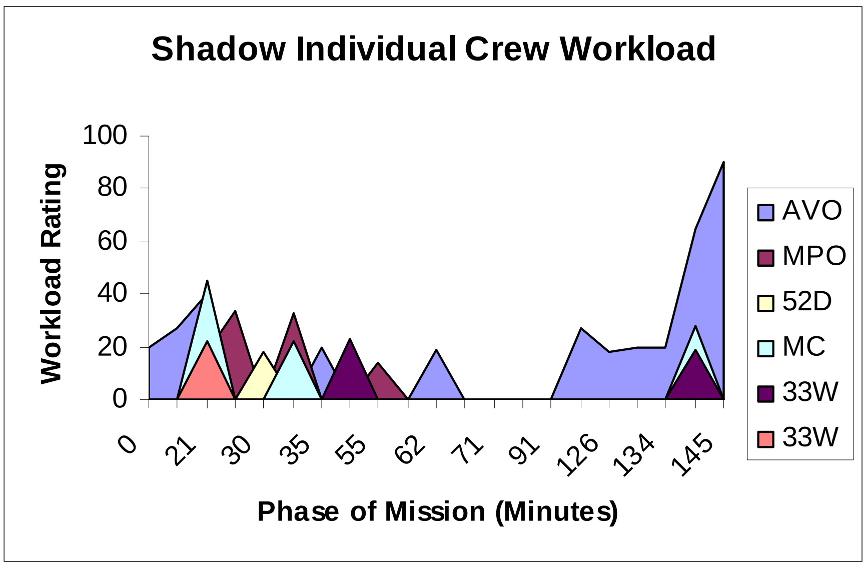

Figure 4. Shadow workload ratings.

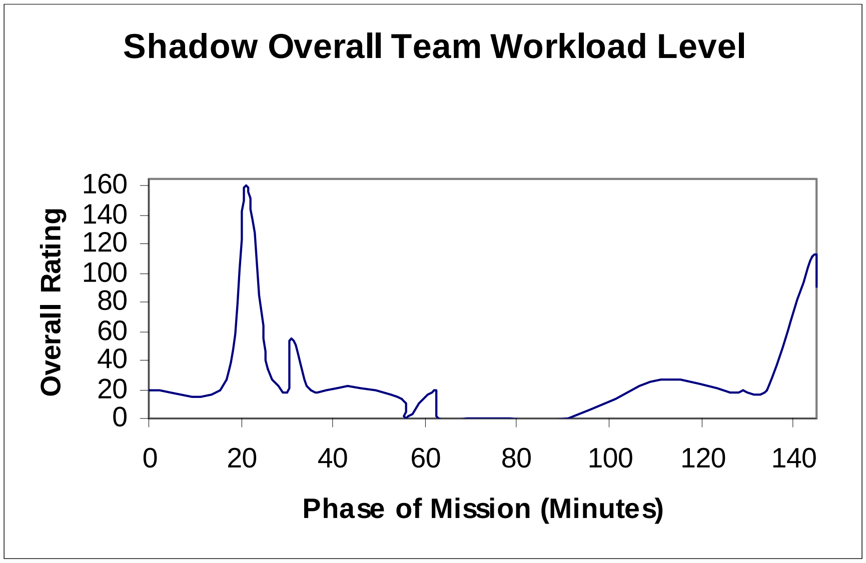

Figure 5. Shadow overall crew workload level.

Figures 4 and 5 can be used to help us understand the nature of the workload commonly experienced by UAS crews, and we discuss each crew member's role individually as it contributes to the mission and the role that teamwork plays in the mission.

The individual crew workload ratings shown in figure 4 indicate that crew workload for the pilot (AVO) is at a peak at the beginning and end of the mission, which corresponds to the duties of take-off and landing. In contrast, the engine mechanic seems to only be involved at a peak in the 21-minute range of the flight, which would correspond to initial engine checks, and setups leading to take-off. In fact, the engine mechanic only appears busy at this time of flight, and his efforts would have to be charted separately from the mission, since his work begins before the mission begins and continues only after the flight mission ends. The MPO has two spikes in workload at the 40-minute and 140-minute markers, and these would correspond to initial sensor use during the mission, as well as activity associated with landing the aircraft. The zero marks on figures 4 and 5 are actually the receipt of the mission. Steps leading to a take-off are shown building to the time frame of about 21 minutes on the figures. Note that all crew members are rating their workload as moderate (at a level of about a 40 rating) in the initial setup and take-off part of the mission. Also in contrast to the rest of the crew, the pilot (AVO) has a workload buildup to very high levels (90 rating range) at the end of the mission.

In figure 5, the same data shown in figure 4 were added together to illustrate the overall team effort workload. For figure 5, the high spikes do not indicate team overload, just the contribution of all the team's ratings to show the sum value of the ratings.

In summary, take-off and landing represent the highest levels of ratings for the Shadow, and it is expected that this workload rating pattern would be reproduced in the new UAS, given similar technology.

It is expected that the shape of the trend line also depends on a variety of variables including the mission tasking received, deviations from the flight plan, number of targets to be acquired, time limits, and maintenance factors.

Conclusions drawn from the Shadow database model in figures 4 and 5 can be summarized as follows:

- Crew scheduling needs to optimize the times when a lot of work is needed (take-offs and landings) and minimize the crew size when it is not needed (en route parts of the mission).
- Specific maintenance activities were not evaluated for this study. In general, maintenance activities are fairly uniform in time content, except when external environmental effects (nuclear, biological chemical [NBC] gear, cold, wind, rain, power outages, etc.) or supply and support disconnections disrupt the workflow. This may lead to less than desirable maintenance practices being employed (jury rigging, part cannibalization, temporary repairs, unsuitable substitutions, etc.).
- Note that the manning values listed are not necessarily in congruence with official Shadow manning values but reflect what operational Soldiers have revealed in questionnaires and interviews regarding war-time manning.

In addition to the data and comments listed, which were condensed from UAS crew questionnaires and interviews, the next step of estimating manning might be to look at mathematical models.

3.7 Mathematical Modeling of UAS Manning Requirements

We developed the following approach by comparing the current manning needs of the Shadow, Hermes, I-Gnat, Hunter, and Predator and then predicting where a new UAS manning might fall, based on interpolation and extrapolation of the manning trend lines of those current aircraft. This approach assumes similar technology with some additional capability in a variety of areas, but that the new capability would be incremental and roughly equivalent to the differences seen in the five current systems shown. This also assumes that the new system would probably be most like Hunter or Predator, that is, a large, long range, sustained operations, multi-sensor platform. All rankings were based on the relative similarity to the new UAS with the use of a multiple attribute rating system. For example, since the Shadow is the smallest UAS, it would be least similar to the Predator in terms of size. However, manning levels, size, or any single variable did not alone determine similarity; the rankings were subjective and included consideration of multiple issues. The results of mathematical modeling are listed in summary: with purely predictive regression models, the manning value range was from about 66 to 75 personnel (see appendix F for all mathematical models). With a linear rate increase based on the AFRL report, if the system were more like Hunter, its personnel level would be 65.72, and if more like the Predator, its value would be 68.2 personnel. Considerable information about mathematical modeling is contained within appendix C, and that section contains a very wide array of models that are supported by an even larger range of modeling assumptions.

3.8 UAS System Maturity and Manning Prediction Comments

It has been mentioned previously that the number of hours is the best reflector of a system's maturity from a safety perspective as well as a human learning perspective. Considering that Predator now has more than 100,000 hours of flight time (and is accruing flight time at a rate of 3,000 hours per month) and Hunter has more than 30,000 hours of flight time, it could be asserted that both of those systems have been adequately tasked in war to the degree that their operation has established a few valid milestones. It is with that thought in mind that the manning estimates for Predator, Hunter, and to a lesser degree Shadow, have been subjectively given more weight in this study than other fielded systems, some of which have far fewer hours. For example, as of January 2005, the I-Gnat had about 3,700 hours and the Global Hawk had about 2,500 hours. In comparison, as of January 2005, the Pioneer had 35,226 hours and the Hermes had about 25,000 hours; however, the Pioneer is considerably smaller than most Army UASs studied. Therefore, it was not factored into the numerous regression models. How comparable is a new UAS to any of the old UASs? If the fit and function of the contenders for a new UAS are very close to those of current aircraft, then estimates derived from current aircraft may fit well; however, if substantial changes have been made in current systems to fit the needs of the new UAS requirements, then basing manning estimates on those current systems could be problematic.

3.9 Manning Limiting Factors: The GCS

One of the most important, organic, limiting factors for a UAS program manning (not yet discussed) is the ability of a GCS to support more than one UAS operation. This affects all DoD UAS services. To date, only the Global Hawk has provided proven, dual UAS operations using a single four-person air crew (Hunn, personal experience, 2004). While this control issue is a focus of initiatives in both the USAF and the U.S. Army, there is currently not a single DoD system regularly using one GCS for the control of multiple aircraft during full operational conditions (this does not include the short-term control hands-off situations which have occurred in operational settings across the services).

The ability of an air crew to manage more than one UAS involves detailed control and display evaluations, crew coordination, and extended training. It also involves a detailed understanding and the addressing of significant human factors issues associated with the performance of dual tasks. Considering that current Army GCS stations require two primary operators (AVO and MPO) as well as the possibility of a relief AVO or MPO (interchangeable duties in the Army), that sets a limit of three personnel per GCS to operate two sets of primary controls and displays. The use of a portable ground control station (PGCS) for short-term interim control of the UAS and data dissemination should be considered in an analysis of new UASs. In the USAF Global Hawk, this issue was addressed several years ago and effective solutions were proposed and accepted for what was called a relief-on-station test with two Global Hawk UASs operated by a single crew (Hunn, personal experience, 2004).

3.9.1 Manning Estimates by GCS and Portable GCS (PGCS)

The manning requirements for a new UAS could also be seen as an issue driven by the limiting factor of the number of GCSs and PGCSs available. However, note that if GCS operations are a limiting factor from a command and control (C2) perspective, that issue can be addressed by three approaches: (a) allow control of the aircraft from the PGCS, (b) increase the number of GCSs, or (c) modify the GCS to allow multiple UAS operations from a single crew. An alternate and complimentary approach to having large numbers of GCSs to accomplish missions is to have that control via automated routines.

The basic principle of automated control is that we can accomplish workload sharing by (a) placing UASs in orbit or on pre-planned flight paths while allowing other UASs to take off and land and then (b) returning control to a particular GCS or PGCS. Prioritization of flight tasking should be a crucial element of UAS C2.

3.10 Warfare Tasking Factors and Manning Impacts

It must be recognized that with variability of mission complexity comes variability in manning. A significant source of risk in making predictions about manning is our not being able to see proposed systems in action, that is, there are considerable risk factors in assuming that any proposed UAS will be easy to use, intuitive, uncomplicated, readily available, reliable, and maintainable. In terms of training, it is being assumed that whatever systems are included in a new UAS will be adaptable to the multiple levels of MOS skill types currently available. The issue of skill level required to meet the need is a common training issue, but this type of issue often affects combat capability, often dramatically.

Mission complexity was referred to in the previous section and can be a significant risk factor in the estimation of manning. The primary reason that this could become an issue is that by themselves, the demands of individual components of new systems may not be excessively tasking, but in combination or in certain battle circumstances, they may result in excessive workload. An example for illustration might involve the following scenario:

> A reconnaissance, surveillance, and target acquisition (RSTA) mission is scheduled for three UASs. In support of a 24-7 mission scenario, three UASs are currently over targets at some distance from the GCS deployed locations. Part of the RSTA missions involves surveillance with light detection and ranging (LIDAR), hyper-spectral, and signal intelligence (SIGINT) collection. By themselves, these three new systems may require significant workload for a new crew, but what effect on workload occurs if during the same mission, the area under surveillance is subject to a chemical attack during a period of inclement weather, say low-level fog or rain? Under these conditions, the UAS C2 functions may be inhibited by the immediate environment, and the sensors may have to be selectively employed or not used at all for short periods of time. In order to assess

this emerging weather threat, a meteorological (MET) pod may be needed to collect ground air flow data, but that MET pod may require additional personnel time in order to process its data, thus requiring selective attention from the MPO who is already tasked with selective switching of sensors to meet the primary mission of RSTA. In addition, the MPO may have to handle cloud-based static or lightning and its effect on SIGINT collection; however, both of these issues may plague the operators of these UAS missions and result in an overload condition not anticipated when capabilities are considered as singular tasks.

The use of deliberate oil fires in recent Iraq military campaigns is an example of a low technology approach used to defeat high technology electro-optical sensors. It can be expected that future UAS operations involving SIGINT collection will typically be subject to electronic jamming, as well as other counter-measures limited only by imagination and available technology. This consideration of battle tactics on operator workload is just another factor in manning estimates.

It is when these potential fog-of-war situations occur that systems design, particularly manning, must be able to cope with the imposed load. This concept is clearly articulated in chemical or biological warfare operations using MOPP when the physiological restrictions of MOPP are known to negatively affect human performance and effectiveness. From the simple standpoint of fatigue, compensations are built into the use of MOPP, and allowances are made for time to complete tasks. Typically, no one would debate the limiting effects of MOPP, but the cumulative effects of information overload and the cognitive demands of working in uncertainty need to also be considered and compensated for in the same way by adequate manning. In this respect, manning levels should, if anything, be increased to some degree to compensate for the uncertainties associated with the integration of new systems, as well as to address the unpredictable nature of warfare. Just as the accident learning trend lines for UASs change with age, the human learning trend line for those systems changes with task complexity.

4. Discussion

Considering the previous information, the following discussion centers on what level of manning is required to meet the specifications for a new UAS.

4.1 Baseline Manning Estimates

The previous modeling and analysis estimates were based on individual crew performance criteria and on the assumption that a crew would be assigned to one aircraft and support normal and surge (24-7) missions. Manning for a new system must consider the numbers of flying missions and operations tempo for normal and surge operations rather than just looking at a static manning level

for all applications. It is also recognized that to keep a group of UASs flying 24-7, a staggered and overlapped flight operation must be conducted. Such a planning schedule has been developed by the UAS U.S. Army Training and Doctrine Command (TRADOC) Air Sensors System Manager (TSM) (Fort Huachuca) and has been considered in this analysis. That schedule considered loading, transporting, assembly, mission preparation, launch, backup, maintenance, and recovery operations. Details can be obtained from the TRADOC TSM at Fort Huachuca. In addition, the historical values for manning have largely been based on the use of Government personnel and contractor personnel who performed AVO/MPO roles interchangeably. In contrast, for some UAS programs, contractors may be expected to contribute more to maintenance operations; in some cases, programs are assuming 100% contractor maintenance levels, and a few programs (I-Gnat) are contractor maintained and operated.

4.2 Consequences of Military Versus Civilian Contractor Manning Allocations

In Predator, contractor manning accounts for about 5% to 7% of the total manning and has been as high as 18%; in Hunter, it was at or above 10%. It is important to emphasize that the manning estimates derived for this report are based on skilled personnel, regardless of military versus civilian affiliation. Maintenance manning estimates should also be based on a wealth of information gained analytically and experientially from combat deployed personnel from several branches of DoD as well as other Federal agencies.

4.3 Maintenance Manning Details

The number derived for manning a new UAS can be based on a systems approach to manning, that is, other UASs have been demonstrated to operate effectively while performing approximately the same duties as shown in the requirements documents for a new UAS. It would be prudent when one is making these predictions to consider ensuing programs and spiral development, known or predictable additions to the system (see appendix G). Transfer of maintenance activities to contractor personnel allows for military personnel who previously performed those duties to be reassigned into roles that are non-maintenance related. The following section indicates some of those possible assignments without placing fixed numbers of bodies in those positions. It is believed that commanders in the field should be involved with this allocation of personnel to suit mission needs, based on mission type.

4.4 Mission Planning

Mission planning will incorporate significantly more personnel than current systems, primarily because as UASs become more sophisticated, more “up-front” planning must be done to complete the mission. This is a common principle for manned aviation, and this planning is primarily in the area of establishing contingencies for individual aircraft based on systems state and mission need. What this means is that rather than performing numerous “on-the-fly” changes in flight path management, the UAS will have to use a larger library of sub-commands

and routines in order to reduce the workload on the AVO and MPO during the mission. For example, currently, pre-planned flight routines would include auto-take-off and auto-land, orbit patterns, and lost link return-to-base commands. In the future, this list of automated routines is very likely to increase to provide more automation capability, which in turn will reduce workload on the AVO and MPO, most likely reducing workload from mundane operational *ad hoc* tasking. As an additional example, if a route change should be accomplished *ad hoc*, the AVO would most likely have to perform a fuel calculation in order to determine if the mission can be accomplished while considering the additional flight time incurred by the *ad hoc* tasking. This type of involvement increases the workload of the AVO, and there is little reason that an automated routine cannot perform the calculation faster and more effectively than the AVO while the UAS is in flight. This entire procedure could have been accomplished by a mission planner before the mission began. In addition, mission planners will be required to plan more for all types of contingencies that might occur during the flight operation.

4.5 Communications and Link Management

New capabilities involving warfighter communications payload (WCP), automatic target detection, recognition, and identification, will require additional personnel to attend to these new requirements. The more automated the system becomes and the more complex its communications links are, and the more likely that personnel will be required to manage those systems. This is the inevitable shift from "hands-on" control to observation and management of systems. This management is not directed toward simply establishing continuous pathways for communication because automatic frequency management will always be faster than manual switching of those links, but rather communication management in this sense is the linkage of sensors of all types to GCS personnel to PGCS to tactical operations center (TOC) to headquarters (HQ) and to external customers of the products being collected by the UASs. This is primarily a human intelligence issue, which is providing the correct linkages of management personnel with the personnel operating the UASs, so that information flow is continuous and not interrupted by conflicting human needs. It is essentially a job associated with crew coordination where the "crew" are extended to the TOC and HQs levels and must be thought of as an extended team rather than external customers receiving products.

4.6 ASTAMIDS, NBC, Surety Materials Sampling (SMS)

These new capabilities will require trained analysts, probably in a TOC or HQ setting; they will be responsible for understanding the implications of data being collected in real time by the UAS. This will also be a very high workload task because information will be coming in real time, much of which will require quick analysis, particularly in the area of NBC and SMS. Decisions, aided by computer analysis routines, will be needed as soon as possible to avoid risk potential for friendly troops on the field. Sampling testing will also require sophisticated computer analysis of results that will be interpreted by some type of analyst, again in a TOC or HQ setting. It is highly

likely that the airborne standoff minefield detection system (ASTAMIDS) will present the analyst with some type of graphic display of mine fields; however, since no detection system is foolproof, that graphic imagery will probably have to be examined in detail by an analyst. Without a doubt, once the attributes of the ASTAMIDS system are discovered by our enemies, the use of decoys and additional concealment techniques will start to be employed in those mine fields, and those techniques will most often be best detected by personnel who are familiar with the human intelligence of those types of deception.

4.7 Communications Security (COMSEC) and Cryptography (CRYPTO)

It is anticipated that maintenance of encrypted communications links of all types will involve additional personnel and additional duties not currently used in current Army UAS communication systems. Manual manipulation of keys, codes, and procedures may entail the need for one or more individuals per company who may do this function full time—a role that is likely to be expanded with future systems. With additional SIGINT capability, the manning needs for COMSEC and CRYPTO are likely to increase over current systems.

4.8 Imagery Analysts

The next generation of imagery analysts will not just be reviewing live video “feeds”; they will have numerous tools available to merge synthetic images (maps, geographical imagery products) with historical data such as navigation maps and virtual imagery (target markers, political boundaries, air defense zones, etc.). Virtual imagery in particular will be computer generated and then overlaid on live video in the same way that current crosshair target indicators are placed on targets. Cursor-controlled virtual imagery will very likely be available by the time a new UAS is fielded. LIDAR, ultra-spectral and hyper-spectral scans will require additional trained personnel, again probably at a TOC or more likely, an HQ setting.

4.9 Manning Discussion Summary

An increase in the number of personnel from baseline Hunter UAS levels is to be expected for a new UAS, primarily because of the increasing complexity and duration of the mission role that the new UAS will be playing. Considering Army manning regulations as a constant (for the purposes of this study), the other factors affecting manning include a recognition that all systems mature over time and thus their accident rates decline independent of the level of manning. In terms of safety, it was shown that for current UASs, manning levels above 55 (Predator UAS) appear to have a reducing effect on accident occurrence (i.e., both Hunter and Predator had significantly lower accident rates than all the other UASs tested), and this is believed to be attributable to a high system maturity plus a fairly high system manning level. Increases in manning for the new system are also warranted because of increased mission length which has negative human vigilance impacts as shown by numerous laboratory studies conducted over decades. Modeling with IMPRINT indicated individual and team workload highs and lows and

indicated a need for field reallocation of personnel to meet mission surges such as take-off and landing. This modeling also revealed that some task reallocation may be considered for AVO and MPO duties, since it appeared that the AVO was being overloaded during landing activities. Mathematical models using a range of variables that affected manning produced numeric manning estimates that averaged 65 to 68 personnel per company-level organization for a next-generation UAS. Numerous regression models of various types, using a wide ranging number and type of variables in both interpolation and extrapolation designs, achieved similar numeric prediction manning values from 66 to 70 personnel per company. Limitations of the GCS and PGCS in terms of UAS flight support were discussed, and suggestions to increase the number of GCS units or increase the number of UASs managed per GCS were also mentioned. Balancing all these factors against unknown technological advances is part of the risk of estimating new system manning. In particular, automation and lower maintenance systems can dramatically affect manning levels and thus engender risk in making manning estimates without hardware being made available to study and test.

It is believed that technological enhancements available to the new UAS, which were not available to current UASs, can reduce some of the maintenance requirements below those used for Predator or Hunter. Heavy fuel engines alone could reduce maintenance manning levels by reducing required inspections. Enhancements and sophistication in GCS control and display design, as well as automated routines built into a new UAS, could reduce manning. However, should operations be extended beyond an initial 72-hour operations tempo to 24/7 for months at a time (such as seen in Predator, Hunter, or Shadow war-time operations), then this estimate for manning would have to be increased to compensate.

The separation of UASs into autonomous units, not all contributing to the surveillance of a single target, is the beginning of fully autonomous functions within a company, complete with split operation sites and mobile PGCS operations that add complexity to the mission. Secondary complications that arise when weapons are added to a new UAS must be considered from a maintenance as well as C2 situation. This latter capability is a significant shift from historical RSTA roles. In addition, the use of a UAS as a communication link is believed by this author to be an interim practice, a practice that will probably conflict with the desire of commanders to provide RSTA or weapons deployment more often than is currently being considered. The elimination of a second UAS from a hypothetical UAS company that is acting solely as a relay station, is very likely considering developments in satellite communication (SATCOM) reliability and availability.

It is recommended that an additional study be accomplished to determine the intent of commanders in the field as to allocation of UASs for specific purposes, that is, given the chance, will a commander in the field employ the few assets s/he has in a passive communication relay role, or will s/he be tempted to increase the use of weapon-equipped UASs over traditional RSTA or relay roles? Given the chance to collect MET data or employ Hellfire missiles, which feature will typically be used? This last series of questions is not meant to be provocative but to

emphasize that a more quantitative emphasis is often placed on assets destroyed over assets surveyed, and this is a significant psychological issue that addresses manning directly. This last issue also points to the obvious direction seen in programs such as JUCAS (Joint Unmanned Combat Aircraft System), which are intended to replace manned attack aircraft. Figures in the appendices display how particular positions on a new UAS could be baselined, increased for spiral developments, or compared with an existing system. The allocation of functions by modification table of organization and equipment (MTOE), MOS, contractor, and as a result of other variables is listed in appendix H.

5. Conclusions

Questions asked in the methods section of this report are summarized in table 4. Significant information is contained within this report regarding specifics for manning estimates, the logic used to achieve those estimates, and the justifications and data required to make those judgments.

Table 4. Questions and answers for the UAS manning study.

Questions and Answers Associated With a UAS Manning Review
What are the manning requirements to maintain and transport the system? These should be consistent with what is proposed in the ORD and TRD
What are the vigilance requirements of the UAS pilot and sensor operator? To address the vigilance decrement expected for this new UAS, it is recommended to reduce time on station in accordance with the flight schedule listed in the text (AFRL study recommendation) and recommend frequent crew rotations, particularly for the MPO position.
For how long a work shift will the ground crew be required to operate? The work shift will be within the guidelines of Army policy; however, a recommendation is made to change Army policy and reduce the *continuous* hours that the AVO and MPO should operate. This would allow more frequent breaks than are currently listed in the regulation. The AFRL Predator study (appendix A) recommendations are considered as good guidelines.
What are the existing or proposed regulations covering work shift schedules? The Army regulations written for UAS operations (AR-95-23) must serve as guidelines; however, changes in those regulations have been proposed in this research report (see figure 2).
Are special physical or cognitive skills required to operate the system? Current crew training requirements appear to be adequate but must be supplemented by additional training for new UAS capabilities, which is not currently being taught.
What level of training is required for each task? It is proposed that training levels for most Army personnel remain at the previous, higher level of 23 weeks and 3 days (Shadow or Hunter UAS), except it is also recommended that command UAS personnel be taught a short course in the new UASs fundamentals before they accept command roles for this new UAS. It is also proposed that an additional study be begun to determine additional training needs associated with the new systems spiral development programs (see appendix B).
What current system most accurately represents the proposed system? In terms of manning, Hunter or Predator, is this study's best estimator for manning purposes: the Predator because of similar capability and proven high flight hours, while the Hunter, through Army experience and technical similarity, seems to be the most similar to the proposed new, long range, high capability UAS, with consideration for new capabilities considered in manning values.
What empirical data are available on the current systems to support comparisons? Flight hours, incident and accident reports, and field surveys of operational troops.
What methods are best suited to predict the qualities of a future UAS? Mathematical and IMPRINT modeling are the best tools available to predict future performance from present UAS data.
What is the most comparable current system manning level? Hunter or Predator, with some consideration given to Hunter because of its long Army history, and some consideration given to Predator because of its very high number of operating hours. Both in terms of operations tempo similarity. Neither system has an absolute advantage over the other in terms of prediction qualities.

What are the surge or war-time manning requirements?
Recommendations were made to increase manning for continuous 24-7 operations by a minimum percentage of 24% to 66 crew per company. This recommendation was driven by mathematical models considering previous 24-hour operations, new UAS capability (considering spiral development plans), the AFRL Predator manning study, operator feedback, as well as IMPRINT and mathematical modeling results. Additional spiral development probably would increase manning to an even higher level.
What are the regulations associated with manning?
Army Regulation 95-23 (Aviation: UAS Flight Regulations [Department of the Army, 2004]) is the most recent reference in this area for the U.S. Army.
What are the physical or psychological factors that contribute to human UAS control performance?
Human vigilance (or the ability to observe information and accurately process it over time) is probably the single most important manning variable for the AVO and MPO positions. Fatigue and loss of vigilant performance is a primary factor in UAS sustained operations.

Data for this type of study can be collected from a wide variety of sources across several DoD services. Recommended sources for this type of study, which have been used in previous studies include the U.S. Army, USAF (in particular, the Fatigue Countermeasures Predator Study), and U.S. Navy as well as the U.S. Border Patrol (Homeland Security Department). In addition, seven separate UAS platforms were evaluated for this manning study, including Shadow, Hunter, I-Gnat, Pioneer, Hermes, Predator, and Global Hawk. Questionnaires, interviews, and on-site observation of missions should be conducted, and information should be gathered from civilian and military operators, designers, engineers, and product managers. Estimates of manning for any new system are affected by a consideration of air crew, military regulations, rated workload, rest and shift needs, vigilance, duty type, various levels of UAS technology, mathematical modeling, and computer simulation.

These various and largely orthogonal factors were combined to reach the recommendations of this report for the new system manning level of between 66 and 68 personnel. Additional recommendations are listed that resulted from information derived from this study. ***It is critical to note that all recommendations derived are considered as <u>minima</u> for manning,*** and to reduce risk in achieving military goals during war-time conditions, it is suggested that the numbers derived be considered as such. Very little goes as planned during war time, and thus a measure of reasonable risk reduction would be to increase rather than decrease the manning estimates derived from this study; however, the premise of this study was to extrapolate from existing UASs, with a strong consideration given to how well current UAS manning is supporting war-time efforts at existing levels. Thus, within the limits of this study, it is also believed that the values derived are reasonable projections of a future Army UAS manning.

6. Recommendations

The range of values being recommended for a new UAS all come with their own limitations and considerations for the effects of training, scheduling, personnel selection, and shift work hours. It is assumed that training for the numerous capabilities offered by a new UAS will be incorporated into a formal training plan before the proposed system matures into a released weapon system.

The new UAS crew size is recommended to be marginally larger than a current Hunter crew for baseline release. Spiral development for the new system is recommended to be considerably larger than for a current Hunter crew. This will be necessary to meet a considerably greater operations tempo, more UASs and GCSs, as well as new system capabilities, which may be proposed in the new UASs ORD. Additional verbal recommendations derived from a previous manning study (extended range/multipurpose [ER/MP] UAS study) are included in appendix I as an example of qualitative recommendations that accrue as a result of the collection of numerous verbal and subjective input which occurs during a comprehensive survey type of study.

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Appendix A. UAS Capabilities

Table A-1. Manning delineation for current UASs.

Personnel	**Hunter (12 hours, four AVs*, three GCS**)**	**Shadow (3 to 12 hours, four AVs [two GCS])**	**Predator (16 to 40+ hours) four AVs, one GCS**	**I-Gnat (12 to 30+ hours, one AV, one GCS)**
Company HQ	14			1
TOC	10	5		1
Launch and Recovery	24	17		*8*
Contractor Personnel	5		4	?
Operations Management/Detachment Commander (DETCO)/Support			1	
GCS operations			3	
AVO	1	1	1	3
SAR Imagery			3	2
Imagery: Data exploitation management personal computer (DEMPC)			9	1
Payload Operator (U.S. Air Force [USAF]) MPO (Army)		4	9	2
Launch Recovery Element Operations	4	12	3	8
UAS OPS (Operations) Cell (USAF) or TOC (Army)	1	10		1
OPS Intel/Collection Manager Officer (USAF), Army Platoon Sergeant launch recovery site	1	1		
Intel Applications			3	
UAS Maintenance		6		
Maintenance Mgt (USAF) Army Warrant Officer	1	1 (TOC)	1	2
Supply	1	Warrant Officer/ Platoon Sergeant	1	
Sensors USAF (specialists) MPO for Army			5	2
Crew Chiefs			5	
AGCS (advanced ground control station)			6	
Communication/Navigation)			4	1
Electric power aircraft ground equipment (AGE)			2	1
Trojan Spirit			6	
SATCOM Maintenance (Mx)			3	
Total (includes duty overlap)	48 + contractor	22	45-55	11-17

Notes:

1. Predator security support for deployed locations is determined by the local Center Commander, Joint Forces Air Combat Command, or Commander, Air Force provides security manpower as required, based on host base security personnel (USAF Predator Flight Regulation). (Contrast with Global Hawk which included 33 organic security personnel + medical technicians and one doctor.)
2. Predator manning based on continuous orbit for 30 days (more than one aircraft available).
3. *As a general rule there is greater interchangeability of UAS Army personnel MOS duties than for the Air Force. Examples, USAF flight crews do not support security details, in contrast, Army deployed personnel are expected to perform security duties and other duties as assigned, in addition to UAS flight operations. Also Army MOS functions are considerably less specialized than USAF Service Codes (AFSCs).
4. Note that specification values for the Predator manning have been reduced greatly from initial specification values (65 to 82) to current operational levels (42 to 55 personnel). Also because of manning limitations, Predator crews in operational settings have been reduced even further to levels in the range of 45 to 48 military personnel.

Table A-2. UAS general capability.

Capability	**Hunter**	**Shadow**	**Predator**	**ER/MP**
Auto Take-off and land		X	X	X
Number of C-130s for transport	6 C-130s	1 C-130 for early entry or 3 C-130s for Maintenance	4 C-130s or 2 C-141s	Equivalent to Predator
Electro-optical/ infrared sensor	X	X	X	X
Mission	Army Division and Corps Level RSTA, and battle damage assess-ment (BDA)	Army Tactical level RSTA, BDA	USAF Tactical level RSTA, BDA	Army Tactical level RSTA, BDA
Hard points	X		Hellfire	Class V munitions
24 Hour Communications				X
MET survey				X
12 hours on Station	X		X	X
Beyond Line of Sight/Non-line of Sight	X		X	X
SIGINT ASTAMIDS				X X
NBC				X
Warfighter Information Network-Tactical (WIN-T)				X
Ground Moving Target Identification-SAR				X

Appendix B. Shadow UAS Operations Survey (IMPRINT Data)

Name______________________

MOS________ Rank_______________

Approximate number of <u>hours</u> you have been assigned to this UAS_______.
NOTE: If you have been assigned to this UAS for <u>very many</u> hours, please put number of <u>YEARS</u> assigned to UAS____________

Please list the amount of time it takes **<u>in minutes or seconds</u>** to complete the following UAS tasks.

(NOTE: If it takes hours to complete certain tasks, list the number of hours and make a note in the comments section.)

If you have not done this task, mark an X in the time required box.

Tasks	Time Required	How many other personnel involved?	Comments
1. Receipt of mission			
2. Mission brief			
3. GCS emplacement			
4. PGCS emplacement			
5. PGDT emplacement			
6. Remote video terminal (RVT) emplacement			
7. Arresting gear emplacement			
8. Arresting net emplacement			
9. Tactical automatic landing system (TALS) emplacement			
10. Launcher emplacement			
11. Rotation of launcher for wind direction change			
12. Air vehicle transport emplacement			
13. Electrical power equipment (EPE) emplacement			
14. Assemble AV			
15. EPE power up			
16. GCS power up			
17. Ground data terminal (GDT) power up			
18. RVT power up			
19. Prepare EPE			
20. Prepare GCS			
21. Prepare GDT			
22. Prepare PGCS			
23. Prepare PGDT			
24. GCS pre-flight check			
25. GDT pre-flight check			
26. AV pre-flight check			
27. PGCS pre-flight check			
28. PGDT pre-flight check			

29. GCS preset			
30. PGCS preset			
31. C4IP addresses baseline			
32. Map loading baseline			
33. RVT pre-operational check			
34. Launcher pre-operational check			
35. TALS pre-operational check			
36. AV pre-flight			
37. GCS pre-flight			
38. GDT pre-flight			
39. PGCS pre-flight			
40. PGDT pre-flight			
41. TALS pre-flight			
42. Launcher pre-flight			
43. AV engine startup			
44. Mount AV on launcher			
45. Remove AV from launcher			
46. Pre-launch			
47. AV launch			
48. In flight target data collection			
49. Artillery adjustment			
50. RVT operations			
51. Crew changes in flight			
52. AVO responsibilities			
53. MPO responsibilities			
54. Control station transfer			
55. AV recovery			
56. AV engine shutdown			
57. System turn around			
58. Preparing arresting gear for next recovery			
59. Inspect AV			
60. Clean and prepare AV			
61. Fuel AV			
62. Defuel AV			
63. Re-launch AV			
64. AVO post flight operations			
65. MPO post flight operations			
66. GCS power down			
67. GDT power down			
68. PGCS power down			
69. PGDT power down			
70. RVT power down			
71. EPE displacement			
72. AV disassembly			
73. GCS displacement			
74. GDT displacement			
75. PGCS displacement			
76. PGDT displacement			
77. RVT displacement			
78. AV displacement			
79. Launcher displacement			
80. TALS displacement			
81. Arresting gear			
82. Arresting net displacement			

Emergency Tasks	**Time Required**	**How many other personnel involved?**	**Comments, how often does this happen (e.g., one time per 10 flights? One per 100 flights)? Give an example of a percen-tage of this event's occurrence. If a particular emergency has never happened to you, please say so.**
1. Fire on ground			
2. AV fire on launcher			
3. Launcher failure			
4. TALS recovery failure			
5. AV generator failure			
6. Engine failure below 2000 feet above ground level (AGL)			
7. Engine failure above 2000 feet AGL			
8. Primary and secondary no report			
9. Uncontrolled flight			
10. Carburetor icing			
11. Global Positioning System (GPS) failure			
12. Stuck throttle (high revolutions per minute)			
13. Stuck throttle (low revolutions per minute)			
14. TALS abort below the decision point			
15. AV high engine temperature			
16. (P) GDT comms fail			
17. In-flight servo failure			
18. Software lockup			
19. Dual uplink failure			
20. Single uplink failure			
21. VERSA modulareurobus (VME*) failure			
22. GCS electrical power failure			
23. General data do not match AV report			
24. Return home menu does not match AV report			
Any other emergencies that you have experienced?			

*VME = VERSA module Euro card bus (a 32-bit bus)

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Appendix C. Vigilance Loss Laboratory Studies

Of the literature cited in table C-1, the studies of Mackworth (1948 to 1950) in the late 1940s and early 1950s are most often cited in the vigilance literature. Mackworth (1948) developed a laboratory test of vigilance for radar operators who were told to detect changes in a clock ticking and to make note when the clock skipped its normal interval of 1-second beats and changed to a 2-second beat interval. This task was designed to mimic a low probability event, such as the detection of an infrequent radar blip on a screen. In that study, the operator's vigilance in detecting these types of events dropped from 15% missed targets at the beginning of the test to 30% missed targets at the end of a 2-hour period. The test results are shown in table C-1 and are reproduced from Wellbrink and Buss (2004).

Table C-1. Laboratory vigilance studies summary (from Wellbrink & Buss, 2004).

Study, Author, and Date	Subject Studied	Conclusion
Mackworth, 1948-50	Task under-loading effects on visual and auditory performance.	During under-load conditions visual and auditory signals were regularly missed during a monitoring task scenario.
Bakan, 1953	Perception of a change in a series of digits over a short period of time (digit target detection).	Significant performance decrement over time with missed signals and slower responses.
Walks & Samuel, 1961; McCormack, 1962; Surwillo & Quilter, 1964; Buck, 1966	Attention over time to mixed types of visual and auditory signals.	Missed signals, slower response to detected signals over time.
Whittenburg, Ross, & Andrews, 1956	Attention loss when warnings are presented with target signals.	Performance declines even with signals and warnings being present.
Bevan, Avant, & Lankford, 1967	Changes in activity during vigilance task performance.	Periodic changes in activity enhance vigilance performance.
Bergum & Lehr, 1962	Effects of rest periods on vigilance.	Brief rest periods enhance performance.
Chiles & Adams, 1961	Guidelines for work rest cycles for vigilance tasks.	Maximum duty period of 4 hours when passive tasks are mixed with active tasks. When a passive task occurs by itself, attention can be sustained for no more than 2 hours.
Wellbrink & Buss, 2004	Performance Decrement	Target detection reduction over time

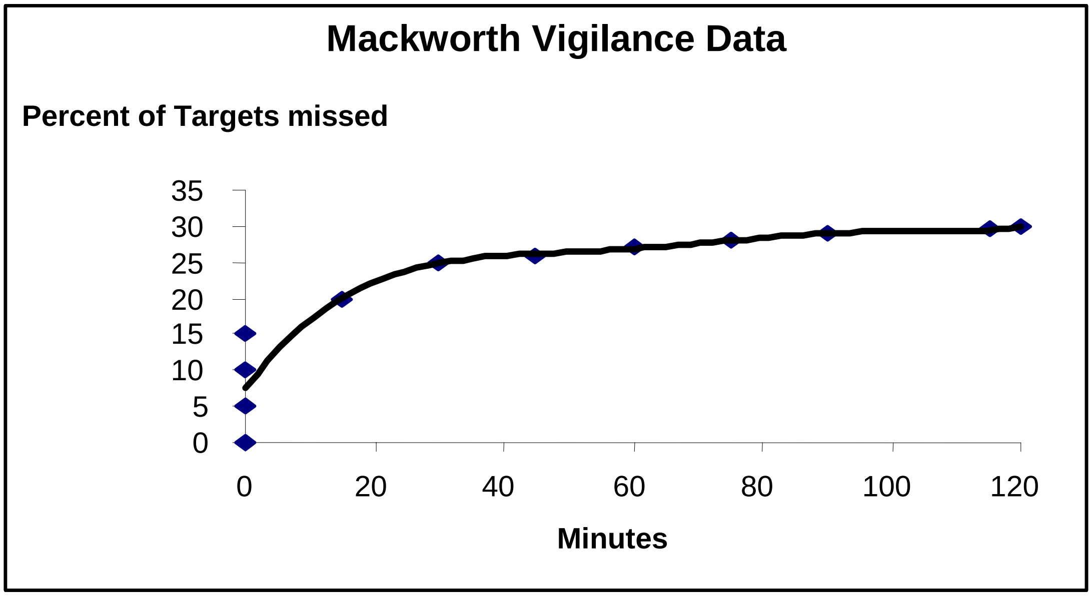

Figure C-1. Mackworth clock test vigilance results.

These data are particularly important from the standpoint of the MPO and secondarily to the AVO. While Mackworth (1948) did not use an actual radar screen, the fidelity of his conclusions has been accepted for decades as reflecting the general trend in the detection of small, infrequent signals (such as visually detecting a hidden target). When infrequent or hidden targets are being detected, the chances of missing such a target in the Mackworth (1948) study begins at a 15% miss rate and proceeds to a 30% miss rate over a 2-hour period. While not exactly reflecting the tasking of an MPO, this experiment showed that vigilance over time, particularly with rare events (similar to finding a hidden, camouflaged or obscured target), is far from an optimal task for human operators to accomplish. It is with this thought in mind that time on task is currently being reduced by many service organizations for monitoring jobs such as the UAS MPO and AVO. Reduction of time on task can directly affect manning estimates and usually results in higher manning levels. It is important to note that the curve shown in the Mackworth (1948) study represents not only Mackworth's (1948) particular test scenario but a general principle that vigilance decreases over time and that assumptions of total vigilance (i.e., no targets missed over time) are not supported in his study nor in any of the studies cited. The conclusion derived from Mackworth (1948) is that job rotation or timed breaks should be a significant part of the manning equation for a new system.

A review of the numerous laboratory studies listed in table C-1 indicates a clear trend toward performance decrements for monitoring tasks such as those of the AVO and MPO. A further review of the vigilance literature shows that at one extreme, the National Aeronautics and Space Administration recommended a duty period of no more than *"30 minutes if monitoring or vigilance comprises the sole task or a major part of the job to be accomplished within that time frame"* (Connors, Harrison, & Akins, 1985). While this level of vigilance might be difficult to

defend as a procedure in an operational military environment, it is indicative of a trend toward reduced duty time when certain monotonous or infrequent tasks are being performed. It must be emphasized that the MPO tasking of looking for *ad hoc* targets is a classic sustained vigilance task, of which, most studies agree, is a poor task for humans to perform over time.

Attention loss is driven by a wide variety of factors including physiology, body activity, state of health, amount of sleep in the days or weeks before, circadian rhythm, nutritional condition, time on station, quality of the imagery presented, rarity of detectable events, motivation and stress, all of which contribute to the level of attention that can be maintained. Little evidence has been gathered about MPO error rates in detecting targets in an operational UAS environment. If a target is missed in an operational setting, there is no way to prove that there even was a target because the only proof that there was a target was its detection by the MPO observer. This is an area where further study is highly warranted. It may be that a single MPO could be working at a very low level of efficiency in actual target detection, but there is little in terms of combat-related studies to show the MPO's effectiveness.

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Appendix D. Training Levels: U.S. Army

Military personnel in the U.S. Army who support UAS operations are drawn from several MOS pools. While the 96U (Air Vehicle Operator) MOS constitutes the primary MOS, other MOS typical designations include 33W (EW [Electronic Warfare] System Repairer), 52D (Engine Mechanic), 96U (Platoon Sergeant), 350U (UAS Warrant Officer), and 35D (Platoon Leader, Lieutenant). Most personnel in Army UAS programs are enlisted personnel, with the exception of the platoon leader who is probably an officer of lieutenant rank (as a note, the lieutenant usually has not attended the basic UAS training school). All 96U personnel are required to go through a typical training period of approximately 23 weeks and 3 days (changed for the Army as of November 2004 to 21 weeks and 3 days). The UAS Warrant Officers are not currently required to go through the UAS training school. Experience levels and age are other considerations along with formal training in assessing the capability of UAS air crews.

Training Levels: USAF

Military personnel in the USAF who support UAS operations are drawn from several AFSC pools. Air operations under Air Force Regulation 51-4 (superseded by AFI 36-2205 [Secretary of the Air Force, 2004]) are currently being reviewed to formalize UAS training, but for the present, the MC or AVO is currently rated as a flying officer. UAS operations in the USAF are treated virtually the same as regular, rated, aviation personnel, and training continues after the initial 14-week training school is completed. For armed UASs, an additional 20 days of classroom and 50 to 60 flying hours are accomplished. The maintenance personnel for USAF UASs fall into the following AFSCs: 2A3X3 (Aerospace Maintenance), 2A4x3 (Aircraft Communication/Navigation Avionics System), 2A4X1 (Aircraft Guidance/Control Avionics System), 2A6X6 (Electrical and Environmental System), 2A1X1 (Avionics Sensor Maintenance), 2A1X7 (Electronic Warfare Systems), 2A6X2 (Aerospace Ground Equipment), 2A7X3 (Structural Maintenance), and 1N1X1 (Imagery Analyst).

USAF personnel supporting Predator operations undergo a 3.5-month training period, with 10 to 12 students per class (Captain Richard Trzaskoma, 11th Reconnaissance Squadron, Chief Standards & Evaluation, personal communication, October 2004). Typical pilot candidates are rated as flying officers, usually with one flying tour of duty before their assignment to the UAS squadron. They are currently from a fighter or bomber assignment (80%) or an airlift or other assignment (20%). For armed UASs, there are approximately 20 days of classroom with 50 to 60 flying hours and a mid-term “check-ride” evaluation. Subjects covered include take-offs and landings, and basic handling, with ensuing areas of reconnaissance, surface attack tactics, strike coordination, and strike reconnaissance. Instructors are generally civilians, except for tactics classes, which are taught by officers. Sensor operators are typically, young, intelligence personnel (Maj. R. Trzaskoma (USAF), personal communication, September 2004). In

comparison, Global Hawk UAS personnel attend 6 months of flight school and have 8 to 12 sorties of missions as long as 36 hours (Hunn, personal observation, 2001). The Global Hawk personnel also run in 4- to 6-hour shifts. Pilot training "washout" rate for Global Hawk is currently about 2% (COL Tom Tibideau, GH Systems Manager, Air Combat Command, personal communication, October 2004).

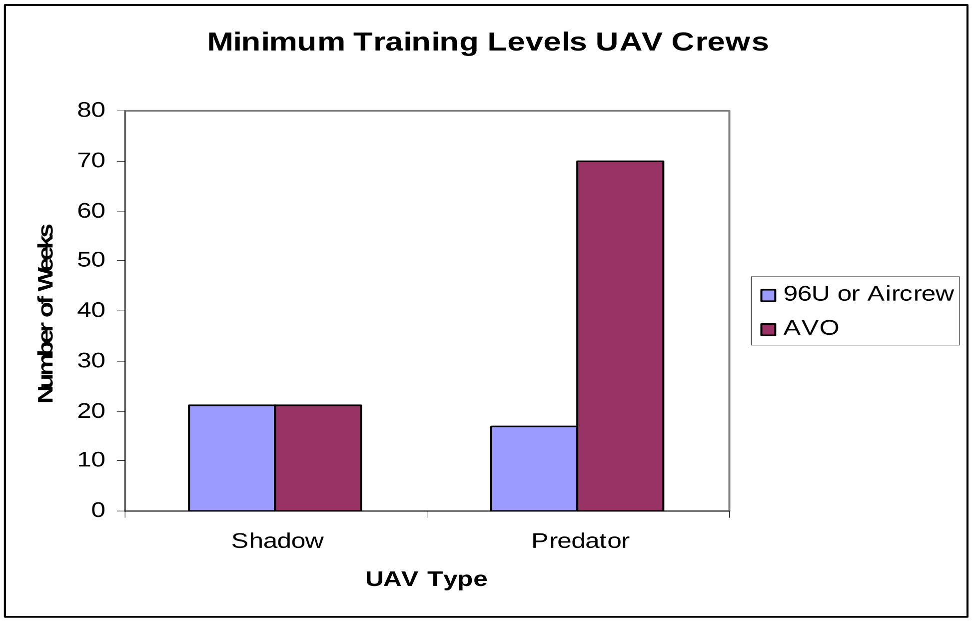
Army UAS Management Personnel Training

It was surprising to find that Army UAS platoon lieutenants, commanders, or warrant officers assigned to UAS groups are not required to attend the same basic UAS training courses that their troops must attend. It was also discovered that there is currently no "short course" or summary UAS course for them to attend in order to become familiar with the operational characteristics of UASs. It is highly encouraged that in order to command such an Army UAS group, officers and senior NCOs become familiar through a formal short course with critical elements of UAS operations, rather than learning exclusively on the job the technical and practical elements of the UASs that they must command. Typically, only warrant officers may have on-the-job experience related to UASs before arriving at a UAS group or may have had several weeks of introduction to air operations before arriving. This is in stark contrast to USAF UAS operations where the AVOs and MCs are rated as flying officers, who are intimately familiar with the air operation environment in which their UASs operate (figure D-1). This experience edge should be emphasized as important to operations, which are both safe and militarily efficient (Tobin, 1999; Howard, 1995). This experience is also reflected in the ranks of the command personnel for both services, with lieutenants commanding UAS groups in the Army and captains or majors commanding UAS units in the Air Force. It is strongly believed that the experience difference in UAS command structure can be an important factor for efficient and safe UAS operations.

Contractor Personnel UAS Manning

Of considerable interest to UAS project managers is the use and cost of contractor UAS crews for flight operations and maintenance. Army and Air Force program managers have commented on the efficiency, utility, and cost of contractor crews.

As a general rule, contractor UAS crews tend to be very mixed in age and experience. Some crews are older and more experienced in UAS operations than their military counterparts, while others are considerably less experienced. Several reasons account for this disparity; they are summarized next.



Typical minimum training levels for U.S. Army and USAF UAS personnel. AVOs for the USAF are rated flight officers with 52 weeks of undergraduate pilot training as a minimum, before they attend the UAS training school of 14 weeks. Additional experience not shown here typically includes a full tour in their primary aircraft before AVOs attend the UAS school.

Figure D-1. Minimum UAS training levels (weeks).

Some contractor personnel for emerging programs, such as UASs, have prior military experience with UASs. This is particularly true for enlisted personnel in the maintenance fields as well as MPOs and AVOs. This trend is primarily because there is no large-scale training currently available for these types of jobs outside DoD, and many contractor personnel are recruited from the ranks of recently separated military enlisted personnel. Economic incentives for this personnel drain from the military are reflected in the comparative salaries of military enlisted personnel versus contractor personnel (contractor personnel salaries are considerably higher). In addition, many junior-level enlisted personnel may have little experience with combat operations (or the military life in general) when they are first assigned to a UAS group. Many UAS personnel are Specialist First Class, Private First Class, and Airman First Class in grades from E-2 to E-4 and sometimes higher. In many cases, the UAS assignment is their first military assignment after basic training. Most Army UAS personnel are recent graduates of flight training programs, and the basis of their knowledge of UAS operations is solely built on formal academic instruction and with limited “hands-on” training. Formal training in the Army UAS School was 23 weeks 3 days, but has been reduced (January 2005) to 21 weeks and 3 days. Currently, availability to fly UASs is strictly limited in the formal DoD schoolhouses, based on higher priority needs for UASs for operational deployments.

Contractor personnel invariably have or have trained in or exposed to a broader range of UAS operations than their military counterparts. This is a shortfall of the MOS/Air Force Service Codes (AFSC) system that is based on specialization. Without the constraints of remaining

within a narrowly defined MOS or AFSC, contractor personnel can perform more diverse duties and thus may be more capable of supporting missions with fewer crew members. This is also a function of experience level and can allow the contractor personnel who are experienced, greater flexibility in task completion. Currently, the Army is attempting to match this specialization problem area by providing more cross training in the 96U MOS classification; however, that training will still need to be broadened to compete with commercial civilian contractors. For example, a civilian contractor may be capable of performing across MOS duties, such as doing maintenance and AVO or MPO tasks, whereas MOS or AFSC separation of duties would not allow that to happen in a military environment.

Prior military experience as a contractor or in the military also provides a more seasoned employee who may have several tours of duty, often in combat environments. This experience, though difficult to quantify, provides a considerable edge over less experienced military or civilian personnel who are approaching their jobs without having had the benefits of that combat experience.

Contractor personnel are more specialized in one regard: in performing only UAS duties. They are not subject to additional military duties, which are often assigned to military UAS personnel, after their UAS flight shifts are over. The types of duties UAS crews are subject to include sentry, Flight Safety Officer (USAF), or non-UAS equipment maintenance, but these duties often detract from the efficiency of the UAS military unit by infringing directly or indirectly on crew rest. This is an area of concern as indicated by numerous military personnel returning from deployments to operational settings. Thus, this additional tasking may detract from the overall effectiveness of a combat operation by limiting the ability of UAS specialists in performing UAS functions only. *It is recommended that UAS personnel be considered as UAS specialists only.*

Commercial recruitment ads for UAS senior flight personnel have recently described job requirements in terms of minima such as high school graduate, with technical certificate, military or community college experience preferred. Federal Aviation Administration certification or schools are listed in the same ad as a “plus,” with five years of experience as a minimum. Additional job criteria requested but not required were certifications as an air frame and power plant mechanic with inspection authorization ratings, private pilot, commercial pilot, instrument rating, certified flight instructor or certified flight instructor with instrument rating, (the latter three were described as desirable). Since the UAS field is rapidly evolving, there is little in the way of formal “credentials” that are involved with supporting UAS operations; thus, there is great variability in the experience and training of commercial UAS crews.

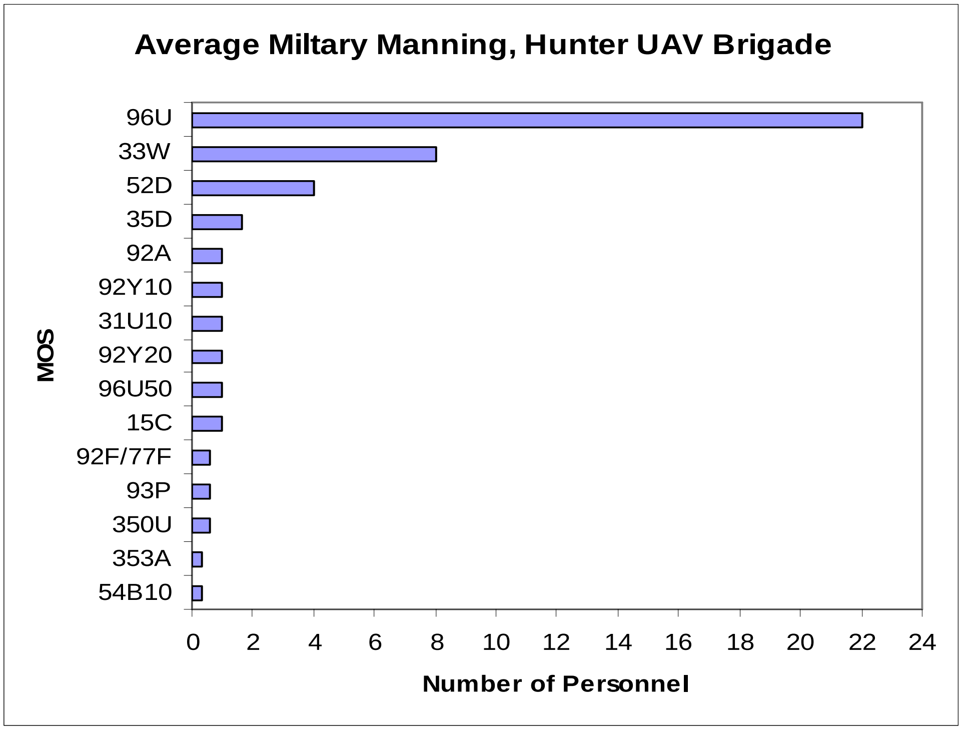
Any crew, civilian or military, will still be subject to basic human limitations as discussed in the vigilance, workload, and physiological sections of this report. Specifically, in chemical/biological contaminated environments, it would be expected that military crews would perform better than purely civilian crews, based on their familiarity with MOPP gear and chemical or biological contaminated work environments. It may also be emphasized that the

comparative youth of the military crews could serve as an asset rather than liability under higher physical or physiological workloads imposed by deployment in environmental extremes. This last issue largely depends on the state of physical fitness of the military personnel versus civilian contractors. An additional factor that does not appear to have played a great role to date but could in future operations, is that civilian contractors are not under the same level of obligation to serve in high risk combat environments in contrast to their military counterparts.

Contractor manning for Predator is often proportionally lower than that used for Hunter, and the battle focus is different in that Predator's focus is on an operational area supported by multiple aircraft from a single GCS. For an example of Predator manning, the U.S. Air Force 332 AEW/46 ERS has approximately 38 military personnel servicing five-armed Predator UASs in the field (plus Combined Air Operations Center intelligence and overhead support at HQ of about 10 persons). This organization also has approximately four civilian contractor support crew, which equates to a 7.25% manning value of civilian to military crew. Across the board, the Predator military manning package system includes 52 military personnel and 3 contractor personnel, which equals about a 5.76% contractor-to-overall team manning ratio. In some situations, the Predator manning ratio has been as high as 18% contractor to military personnel. As a side note, Predator is also evaluating multiple UAS C2 operations from a single GCS as a manning reduction effort. Table D-1 and figures D-2 and D-3 show typical manning levels and positions for Army UAS units.

Table D-1. UAS MOS descriptions.

MOS	**Description**
96U	UAS Operator
33W	Intelligence and Electronic Warfare (IEW) System Repairer
52D	Power Generator Mechanic
35D	Executive Officer (Lieutenant)
92A	Automated Logistics (Specialist)
92Y	Armorer
15C	Company Commander (Captain)
92F/77F	Petroleum Vehicle Operator
93P	Avionics Operations Specialist
350U	Operations Tech mission planning
353A	Maintenance Officer (Warrant Officer)
54B	NBC NCO (Private First Class)



Note: Data compiled and averaged from A/1st MI BN, A-15 3rd Corp, and A224th 18th Corp. Data based on brigade strength as of July 2004.

Figure D-2. Average military manning Hunter UAS brigade.

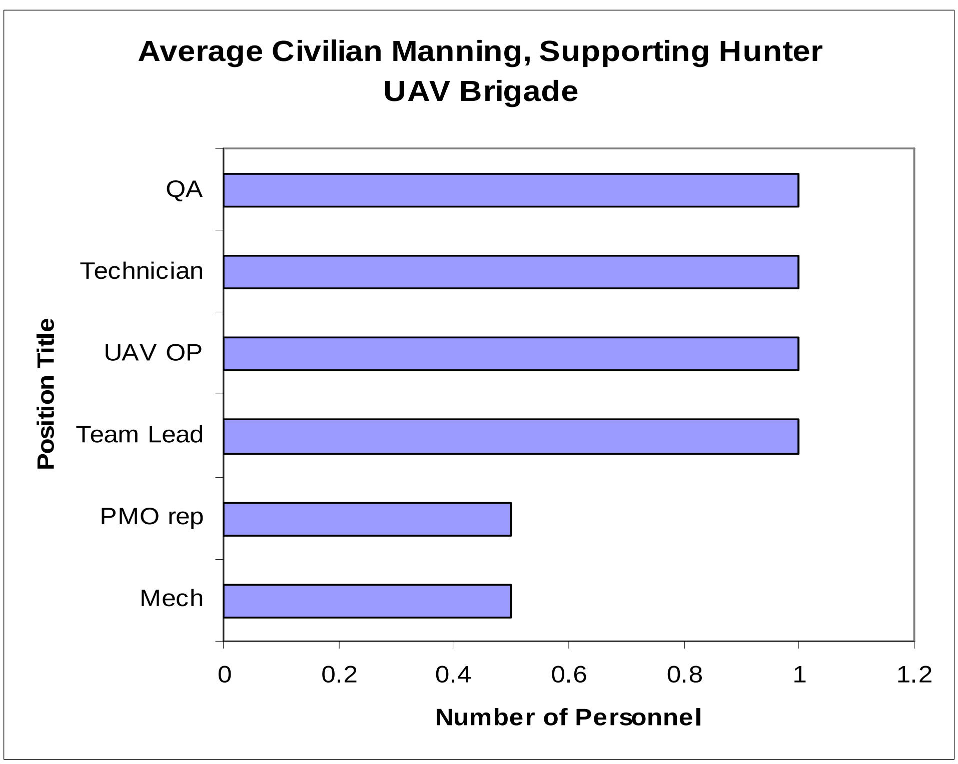


Figure D-3. Average civilian manning supporting Hunter UAS.

Military Manning Adjustments and the MOS

For a new UAS program, certain functions, which are currently being completed by military MOS maintenance personnel, including airfield operations, fueling, and launch and recovery may be assumed by contractor support personnel. This would result in a shift in roles for some of the civilian personnel, notably away from the AVO position and mechanical technician positions to jobs involving fueling and airfield operations. Contractor personnel could replace the 77F MOS, and that civilian position would then become an airfield operations position. Some supervisory duties on the contractor side could also be eliminated if the 350U MOS accepted the same authority that the civilian contractor team leader had, although that would place a military warrant officer directly in charge of civilian personnel.

Military Manning Within Aviation Brigade Reorganization (Post Script, August 18, 2005)

Recent reorganization efforts within the Army have moved management of UASs from the MI brigade structure to the Army Aviation organizations. In the short term, this may be disruptive in terms of MOS designations and duty descriptions; in the long term, it is expected to increase aviator professionalism, reduce accident rates, and enhance training level for personnel assigned to maintain and operate UASs. Certain flexibility will need to be built into this change so that duties and roles previously assigned to MOS 96U (and other MI MOS designations) can be transferred to corresponding aviation MOSs. It also assumes that there will be flexibility in MOS designations so that the dual roles of 96U personnel as either AVO or MPO will not affect (dramatically increase) manning levels.

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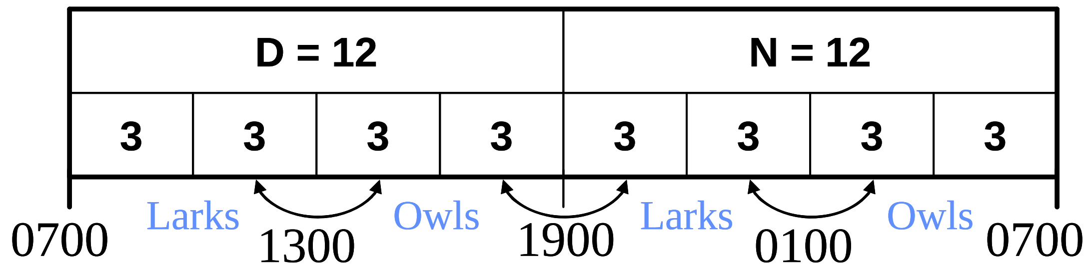
Appendix E. AFRL Predator Manning Schedule Change Recommendations (taken verbatim from AFRL report)

“Chart for overall scheduling*



** D=Day, N=Night, Larks=day shift, Owls=night shift*

Figure E-1. Proposed shift structure containing a 12-hour day shift (D), a 12-hour night shift (N), and 3-hour mission blocks within shifts. The first two mission blocks of a shift are the nominal responsibility of a “lark” Element and the last two mission blocks of a shift are the nominal responsibility of an “owl” Element. Crews may flex across the “lark-owl” and D-N boundaries.

Each crew should fly two mission blocks in one D or one N shift, for a total of six flying hours per shift. A crewmember may be available for up to another three hours of additional duties in a D or N shift. Crews in the “lark” Element of a flight should fly the first mission blocks of the D and N shifts, beginning at 0700h and 1900h, respectively. Crews in the “owl” Element of a flight should fly the last mission blocks of the D and N shifts, beginning at 1600h and 0400h, respectively.

By arrangement between Element commanders within a flight, crews may flex across the “lark-owl” boundaries within the D and N shifts at 1300h and 0100h, respectively. By arrangement between Flight commanders, crews may flex across the D-N boundary at 0700h and 1900h.

Shift Alignment. The 8-day cycle interacts with the 7-day week to come out even at 56 days (table E-1). The 56-day rotation occurs exactly 6.5 times in each 364-day shift work year. Thus, each flight experiences exactly 6.5 rotations per year. There are eight types of weekends (table E-1), and all crewmembers experience exactly the same numbers of each.

In any given 24-hour period, one flight covers the 12-hour day shift with two Elements, one covers the 12-hour night shift with two Elements, and the other two Flights are on recovery day (R)**,** stand-by day (S), or free days (table E-2). Note that crewmembers are only available on stand-by every other day. If needed for special activities, it is arithmetically possible to swap an S day with the preceding free day and sustain schedule equity. However, this is a poor way to manage the crews; the contiguity of the free days is valuable with respect to morale and retention.

Table E-1. 56-day shift rotation for one flight, where D is a day shift, N is a night shift, R is a recovery day, and S is a stand-by day. The eight types of weekends are shaded.

Week	**M**	**Tu**	**W**	**Th**	**F**	**Sa**	**Su**
1	D	D	N	N	R	-	-
2	S	D	D	N	N	R	-
3	-	S	D	D	N	N	R
4	-	-	S	D	D	N	N
5	R	-	-	S	D	D	N
6	N	R	-	-	S	D	D
7	N	N	R	-	-	S	D
8	D	N	N	R	-	-	S

Table E-2. Two cycles (16 days) of shift rotations across four flights, where D is a day shift, N is a night shift, R is a recovery day, and S is a stand-by day.

	Flight			
Day	**A**	**B**	**C**	**D**
1	D	-	R	N
2	D	S	-	N
3	N	D	-	R
4	N	D	S	-
5	R	N	D	-
6	-	N	D	S
7	-	R	N	D
8	S	-	N	D
9	D	-	R	N
10	D	S	-	N
11	N	D	-	R
12	N	D	S	-
13	R	N	D	-
14	-	N	D	S
15	-	R	N	D
16	S	-	N	D

Manning Ratio. In addition to the number of crewmembers within an Element needed to operate all control stations and the operations center, manpower is needed to cover deployment, temporary duty, annual leave, and illness. The percentages associated with these requirements were determined to be 10%, 5%, 8%, and 1%. Thus, each Element should be manned at 124% to accomplish its mission.

Advantages. The adoption of the specific shift work recommendations, above, should provide schedule equity and predictability, and better quality time off for the crews. In turn, one may expect fewer on-the-job errors, increased morale and less management attention spent on individual workers' schedule changes. In fact, "scheduling" *per se* will not be needed, the rotation continues automatically into the future. Element and Flight commanders should manage schedule changes and flexing."

Appendix F. Discussion of Mathematical Modeling Methods

The greatest risk in predicting future manning with a mathematical model is the accuracy of that model, both internally (variance within the model) and externally (its ability to predict the future). Any type of predictive modeling equation depends on the amount of data (number of valid data points or samples), the variability inherent within those data, and the assumptions of the model. In the case of predicting the future of any system, many assumptions must be made about the trends identified in the data, and those trends must continue into the future in order for the model to be a valid match for the future system. In the case of UAS manning, the number of current UASs is very small, and since that sample size is small, the ability to predict a future trend is not very robust. For the purposes of discussion, a manning level that was the equivalent of one ranking higher than the highest ranked system (Predator) was the limit for prediction of future UAS manning for this study. Any prediction above known data is risky; however, limiting the predictive manning values to the closest interval above the highest ranked sample in the data set was an assumed and necessary risk in order to predict a future manning trend and to satisfy the question of "How many personnel will the new UAS require?". Additional modeling assumptions are discussed throughout this report, and those assumptions address increasing the robustness of the prediction by considering a number of factors that mitigate and control the data being used; those assumptions follow in the next sections.

Two separate regression model approaches were used for the projection of manning for a new UAS: conventional linear regression (used when ratio scale data were available), and non-parametric rank regression (when nominal scale data were available). Commonly, a linear model was used; however, other models were tried such as exponential, logarithmic as well as power function models. A regression equation was created with Excel[1] and when those equations were plotted, a trend line was generated and plotted in the text. For linear models, an R^2 value is shown as a measure of goodness of fit; no R^2 value is shown for nonlinear models since those models have no y-intercept as the linear models do, and an R^2 for those models may have an inflated value (closer to 1) for several technical reasons. For the purpose of technical content, all linear models used an Excel formula for calculation of R^2.

The second approach used was to perform a regression on ranks (see table F-1 for ranking criteria) for predictive variables that were nominal scale in nature. This procedure is often used in the social sciences for subjective data (such as subjectively derived ranks). This approach included subjective rankings of UASs on variables that were not ratio in nature (such as their similarity to a proposed UAS). For example, in this report, UASs were ranked by a UAS SME (the author) from 1 to 5 on a subjective scale of similarity to the newly proposed UAS. This

[1]Excel is a trademark of Microsoft.

ranking was based on a multi-dimensional attribute scale, and the rater considered several variables (table F-1). These variables related how each candidate UAS was more or less similar than the proposed UAS. Further studies may consider the approach of having a panel of SMEs provide ranking and then use an averaging procedure to convert their rankings into composite ranking scores; however, for this study, time limited the ability to collect such data.

Table F-1. Subjective ranking criteria for rank regression models.

Ranking Criteria (factors considered in overall numeric ranking [not prioritized])
Manning based on 24-hour operations (similar to, greater than, or less than proposed UAS?)
Risk associated with small UAS sample considered
Increasing technical capability (sensors, payloads)
Numbers and types of missions
Incremental increase or decrease in technology and or number and types of capabilities
Interface or system sophistication for each system
Top two ranking UASs of the series must be Hunter or Predator, since they are most similar to the proposed new UAS (evolutionary development consideration)

Rank regression modeling has been used for at least 25 years in cases when ratio scale data are not available. The rank regression method is detailed by Iman and Conover (1979; 1989). This method allows for a regression on ranks (sometimes called a rank transformation process), which uses an x and a y variable where one or both of those variables are not necessarily ratio scale data. In any case, the use of a rank regression has the same predictive values as a conventional regression but relies on the non-parametric approach of regressing on ranks and not on ratio scale data. In contrast, it does not provide P (probability values), nor does it generate confidence intervals or confidence bands. In addition, with nonlinear models, the corresponding equations have no y-intercept term so no R^2 value was shown.

Regression is a common statistical procedure based on parametric data; however, rank regression can be used as a valuable replacement if the data being analyzed do not fit the assumptions of a conventional parametric regression. Specific references to rank regression are given in Iman and Conover (1979 or 1989). These technical papers detail the use of monotone regression using ranks and the rank transform in regression. Additional discussion of regression on ranks compared to isotonic regression is covered in Cryer, Robertson, Wright, and Casady (1972).

Essentially, the rank regression process used in this report is where y is a normally distributed variable (manning levels) and x is a nominal scale discrete variable (the rank of various UASs on a subjective, composite dimension, such as similarity to the proposed new UAS). An ordinary least squares approach is applied to the ranked (nominal scale) data and numeric values for manning of each UAS. The computations were performed by an Excel spreadsheet program. The Excel program also had a feature that allowed at least four trend lines (with different equation types) to be fitted, and an extrapolation could be made to one unit above the highest level found within the data. While information of the regression of y on x is technically only available within the observed range of x, the objective of a monotone regression in this case was

to predict E(Y/X = x) and not just to fit points in the sample. Other regressions only modeled results within the data set and were thus interpolations rather than extrapolations.

Many of the linear models presented had R^2 values along with the graphic plots. In general, the use of the R^2 has some benefit in interpreting model fit, but as the number of personnel increases, it may be that the final point in the series is becoming an outlier, and since the line must approach that outlier, that data point can increase R^2 without accurately reflecting most of the data. Since R^2 is 1 minus a ratio of the error sum of squares to the total sum of squares, it may be that the error sum of squares is being masked by an increase in the total sum of squares with increasing personnel. In this regard, the use of R^2 values may be influenced by the relative number of personnel for the outlier UAS. In some of the models chosen, the R^2 values are only different at the third significant digit level, which may imply the model differences are negligible. Since the R^2 is a mathematical ratio, it does not depend on the model assumptions; its use as a diagnostic tool is valid if used in a relative comparison manner. Within this study, the emphasis is primarily on big differences in R^2 in different models and not minor changes in R^2 that are only noticeable at several decimal places.

In the nonlinear modeling, no attempt was made to report R^2 values, conduct statistical hypothesis tests, report p values, or establish confidence intervals since those would not be valid in a statistical sense.

Prediction beyond a sample's data is always risky; however, if given a good model, our ability to predict should be enhanced, as long as the prediction is not made too far from the original data set and statistical and logical checks and balances are employed in the process. While numerous approaches can be used to achieve a goal of prediction, it is believed that the rank regression may be one of the simpler procedures. Prediction of future events involves considerable risk; however, prediction of a new system's manning level is the goal of this report. It is also recommended that when this type of task is undertaken, it is desirable to make a prediction that is as conservative as possible. Limits in the amount of data available precluded a multivariate regression approach and resulted in focusing on a few variables of interest. The objective of this study was to explore correlations and not to determine the definitive causality of all effects associated with manning.

However, in order to compensate for risk in predicting beyond the level of the reported data, which was done in some of the models, several models were created that contained data well within the manning levels of the current UASs studied. One model had Predator B manning estimates included, while the other had the actual war-time manning values associated with the Global Hawk's operation. These two model approaches were used to increase the content validity of the modeling approach and to help validate the predictive models mentioned previously. This approach was basically included to mitigate the risk in trying to predict beyond the range of data of other models and to show rough concurrence of interpolation models with extrapolation models using available data. This approach of validating the earlier models with subsequent data was analogous to a split/half approach, where additional data can be used to validate a model that does

not contain those data in the initial data set. Concurrence of the various mathematical models, regardless of origin, was also very good, with a median value range of approximately 66 to 68 personnel being predicted for the new UAS, regardless of method chosen.

Numerous other orthogonal methods were also used to predict manning levels, and those were compared in this study's text with these statistical methods. It is strongly believed that if several orthogonal methods can achieve approximately the same goal, then that conclusion has a higher level of content validity.

Numerous regression model approaches were used in this study to extrapolate a trend and a value slightly above the known data (one ranking interval as calculated by the Excel program). Other regression models used UASs such as the Predator B or Global Hawk, which have considerably more personnel than any of the current UASs studied.

Model Fitting Preliminary Approach

Figure F-1 shows three different generic types of mathematical models fit to the ranked data.

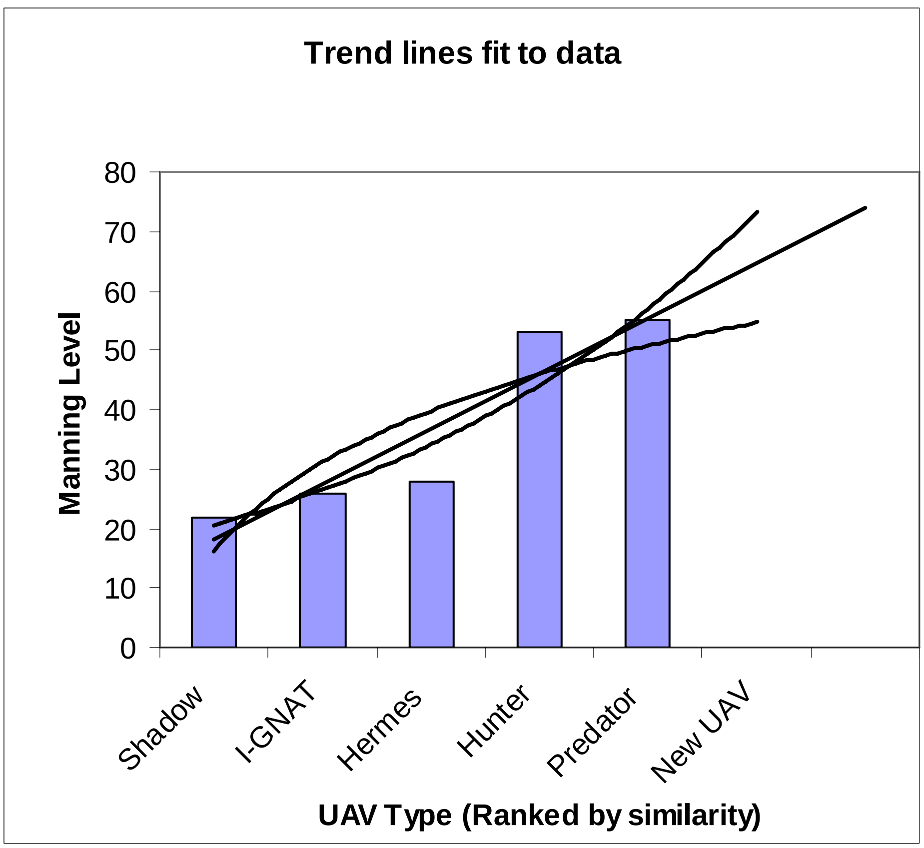


Figure F-1. Three types of trend lines fit to manning data.

Three generic model equation types were fit to the data (figure F-1) and can be interpreted in various ways, each with implications for an extrapolated manning prediction. The first model, shown as the lower line on the graph, reflects a logarithmic trend line fit (a similar trend line

resulted from using a power trend line fit). The logarithmic trend line indicates a manning level that decreases with increased UAS similarity (to the proposed new UAS). The likelihood of this trend line being able to accurately predict manning would probably depend on a system that had a more sophisticated, user-oriented design that required fewer personnel than current systems. While this outcome is possible, one of the assumptions given for this analysis was that the level of technology would be incremental and not likely to result in a major technological change that would necessitate fewer personnel than current systems. Still, this logarithmic model approach might be a good estimator, given technological enhancements that decreased manning needs. This model would be useful in estimating systems that have low manning levels and lower costs.

The second model is a linear model that represents the least change in an extrapolation manning trend prediction. As such, the linear model is conservative in its prediction trending neither toward high or low manning predictions outside the range of known data.

The final model (shown highest in figure F-1) is an exponential model that has the highest level of manning of the three models. This model represents the manning extreme on the high end and assumes manning significantly higher than current UASs. This model could be considered as suitable for situations that represent high levels of unknowns or represent issues such as attrition from combat losses. It also is the highest cost model in terms of requiring more personnel than may actually be needed.

It is difficult to choose which model best represents the data for any particular system. An over-specified system (too many personnel) could be very costly in terms of personnel selection and training (an exponential model was mentioned previously as representing this situation). In addition, an under-specified system (such as the log model may result in a system that is understaffed) may fail to provide a buffer for unforeseen events, but conversely could also result in a lower system cost because of fewer personnel.

There is no clear choice in selecting a model that predicts a future value. It is recommended for this study to use a model that is neither too high nor too low in manning. Such a model should represent a manning growth pattern that would indicate an evolutionary system design rather than a revolutionary design (in a positive or negative manning-growth or reduction direction). In this case, the recommendation would be to consider the range of values predicted by any such model type chosen (exponential, logarithmic, linear) and report that range or to choose a modeling approach that overall represents a mean-based approach; in this study's case, that would be a linear model approach.

It is believed that the selection of the linear model as a baseline estimator will provide a prediction that is neither over- nor under-specified, and thus is moderate risk. The consequences of too many personnel versus too few personnel for a system are a significant challenge in predicting manning for a future system. In order to resolve this issue further, it might be wise to include in the study more UASs if possible, and thus have more data to predict from, or to rely

on one or more independent sources of manning data predictive estimates (such as the AFRL study cited in this report).

Assuming that the linear model suits the purposes of predicting the best of the models chosen, then the next step is to discuss some of the assumptions of this approach.

Method Assumptions and Approaches

Assumption 1

One primary assumption made in this approach was to equalize the manning for all the UAS platforms to support a 24-hour operation, an assumption that already holds for the Predator but was less applicable to the other UASs studied.

Assumption 2

Another assumption is that because of the nonlinear nature of some of the data, that is, because of the dispersion in manning values for the five systems chosen, a rank-based regression would provide a more robust solution than a conventional parametric procedure for some of the models chosen. (The issue of non-normality was broached by some of our statistical experts, and a plot of the manning data might suggest a non-normal distribution of manning.)

Assumption 3

Mission capability of the new UAS should be equal to or greater than that of the most sophisticated UAS on the list (e.g., Predator). However, if the focus is on Army-only systems, Hunter would probably be considered to be the most comparable system overall.

Assumption 4

The number of missions and mission types will probably be greater for the new UAS than for all the other UASs studied (including Global Hawk). Based on the new system's ORD-specific numerical or percentage values that could be associated with specific capability, impacts may be considered.

Assumption 5

The technical sophistication of the new UAS should be higher than for Hunter or Predator, thus requiring greater training and skills or additional numbers of trained personnel; however, the new system will also likely have newer technology than Predator, and that may involve reducing manning needs in comparison to current systems. Additional specialists may be needed to exploit new UAS capabilities. New systems being promoted in research and development such as WCP, ASTAMIDS, new weapons, or NBC detection may be included in the system specifications for the new UAS. Currently, these new specialists and possibly new MOSs are not even available for the missions of Shadow or Hunter (neither are they available for Predator, in corresponding AFSC equivalencies). Training programs may need to be modified to expand the level of air crew

personnel training, with or without a new MOS added to the new systems crew list. It is an established fact that Army enlisted personnel currently do not have the same level of airmanship training/ experience as USAF rated pilots; thus, the new system may require more personnel or higher levels of training for existing personnel or new MOS classifications, and this factor should be considered. Comparisons to other services' UASs (such as Predator) should be strongly considered.

Assumption 6

The level of interface sophistication for the new UAS will probably be unknown; thus, manning estimates should be made conservatively until the system can be subjected to initial or developmental testing. The ranking procedure also assumes that the new system will have roughly the same level of technical sophistication or better than the latest production UAS of this type (Predator).

Assumption 7

If there are two leading contender current systems (e.g., the top two that are most similar to the proposed system), it might be a warranted assumption that one or the other of those systems will be used as a pattern for the new system. In the case of predicting the next system that follows a simple design model of its predecessors, that would probably be Hunter or Predator (this assumption was drawn directly from the ER/MP program).

Other Regression Model Manipulations

Once the approach of using a linear model overall was assumed, then linear models were generated and the fit of those models to the data was observed, while additional model manipulations using "leave out" (sic) as well as a "shift-in-rank ordering" were tried. The "leave out procedure" is a regression tool that takes the data set and removes one set of UAS data for a specified theoretical reason and then observes the effect on the resultant model and model fit.

The "shift-in-rank ordering" manipulation systematically alters the rank order, also based on subjective criterion (a specified theoretical reason) (e.g., the ranks of Hunter and Predator were exchanged, with the assumption being that in one case, the Hunter would be more like the new system than the Predator, and vice versa). Using this latter approach, the effect on the system manning by assuming that overall system characteristics were closer to or farther from the new UAS would provide a different numeric outcome or a change in the point of view as to what would be the best level of manning.

The Leave-out Method of Rank Regression Models

The following models omitted or left out particular UASs to test and see what the outcome on prediction would be for each UAS omitted from the model. This method should be used with caution with small data sets, since each point (UAS manning level) in such a small data set carries a considerable amount of information with it. By eliminating a UAS to test a theoretical

assumption, such as UAS "A" is more like the proposed UAS than UAS "B" is, a significant part of this small data set is lost to the model testing process. Consequently, only a few leave-out models were evaluated. The baseline model manning estimate (figure F-2) had about 65 personnel and an R^2 of .8591.

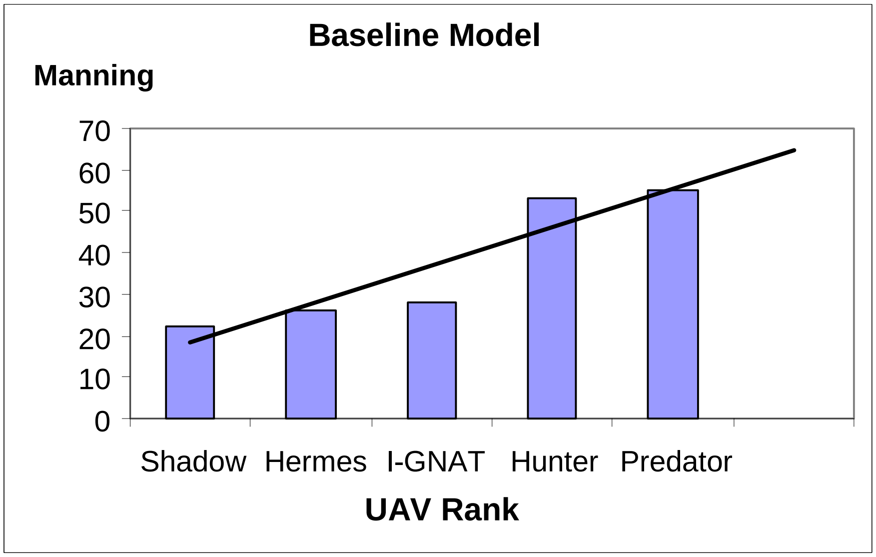


Figure F-2. Baseline UAS manning model.

The first model for the leave-out test approach has dropped the Shadow as a data point. The reason for this was that the Shadow is considerably smaller and has considerably less loiter time than any of the other UASs chosen. The model, sans the Shadow UAS, is shown in figure F-3.

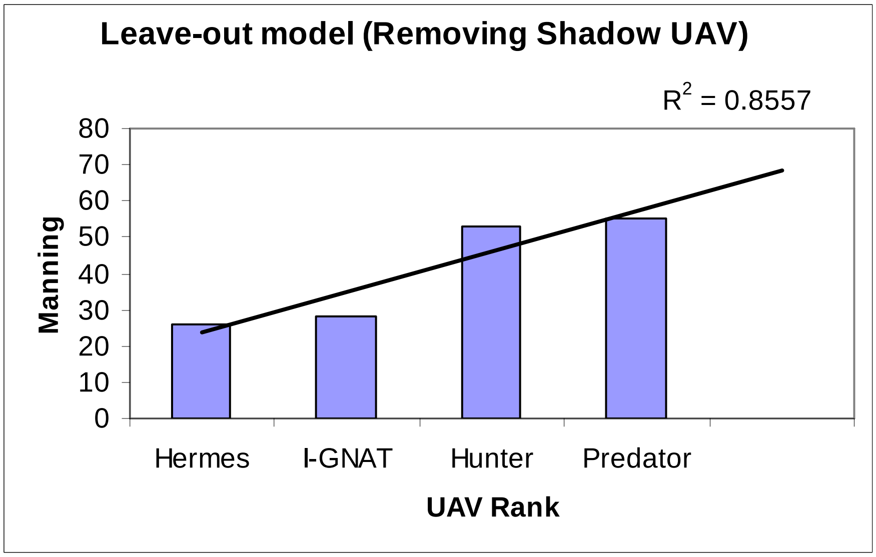


Figure F-3. Regression model, leaving out shadow UAS.

This model (figure F-3), which does not include the Shadow UAS, would predict a new system UAS manning level of 68 to 70 personnel with an R^2 of .8557. This value is not very different from the baseline model and might be an indication that the elimination of the Shadow has little effect. A possible reason for such an outcome might be that the Shadow is very different than the new UAS, and its inclusion in the model in the first place is not really valid. Now for comparative purposes, examine a model that will omit the most comparable UAS in the series (the Predator).

On this leave-out model (figure F-4), the personnel level is approximately 55 to 57 but the R^2 is only 0.7613, a value that is considerably lower than the baseline model or the model with the Shadow removed. The elimination of the Predator might be made on the grounds that it is an Air Force UAS and not operated by the Army; thus, it was not representative of Army UASs. However, deleting the UAS which is considered to be most similar to the new UAS had the biggest R^2 effect on the model, as well as the most dramatic reduction in manning of any approach tried so far. The leave-out approach thus illustrates that the closer in ranking the UAS is to the new UAS, the more effect it has on the model.

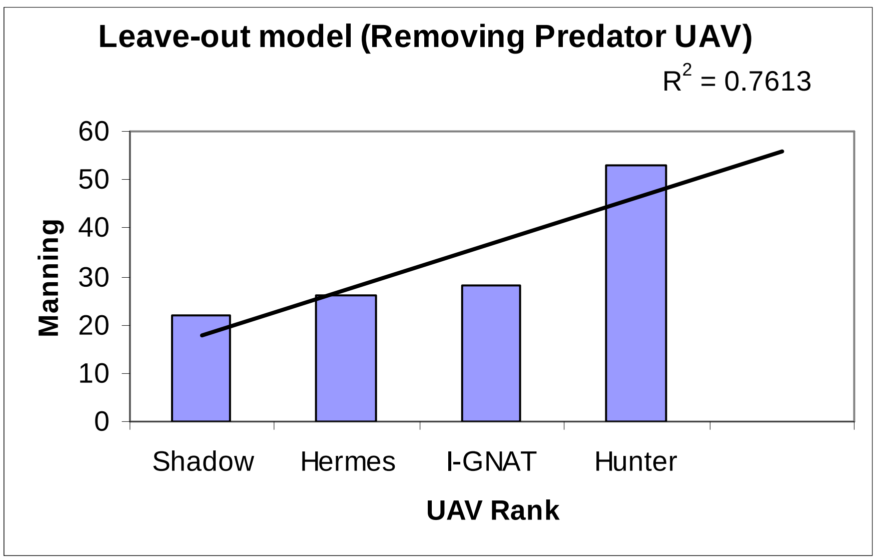


Figure F-4. Regression model, omitting shadow UAS.

The Shift-in-Rank Regression Models

The next approach (figure F-5) looks at changes in model output by shifting the order of ranking. In the first model of the shift-in-ranking approach, an assumption was made that the new UAS will be more like Hunter than Predator. This consideration could be made on the basis of the ease of the system to be built, using Hunter as the most comparable current UAS rather than Predator.

This model shows the difference of ranking Hunter as more similar to the new UAS than Predator. Results for manning are values about 66 with an R^2 of 0.8225 compared to manning of

about 66 and an R^2 of 0.8591 in the baseline model (figure F-2); this shift in ranking had very little difference.

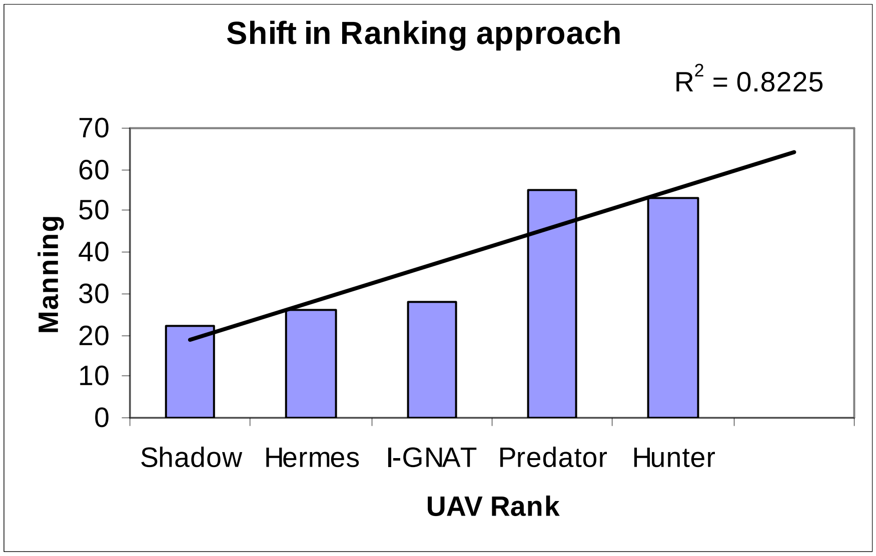


Figure F-5. Shift in ranking model, predator reversed with hunter.

The last shift-in-ranking approach might be to change the order of the Hermes and I-Gnat while maintaining the order of other UASs.

The reversal of the Hermes and I-Gnat (figure F-6) has little effect on the model with a manning level of about 66 and an R^2 of 0.8225 versus the same level of manning and an R^2 of 0.8591 in the baseline model.

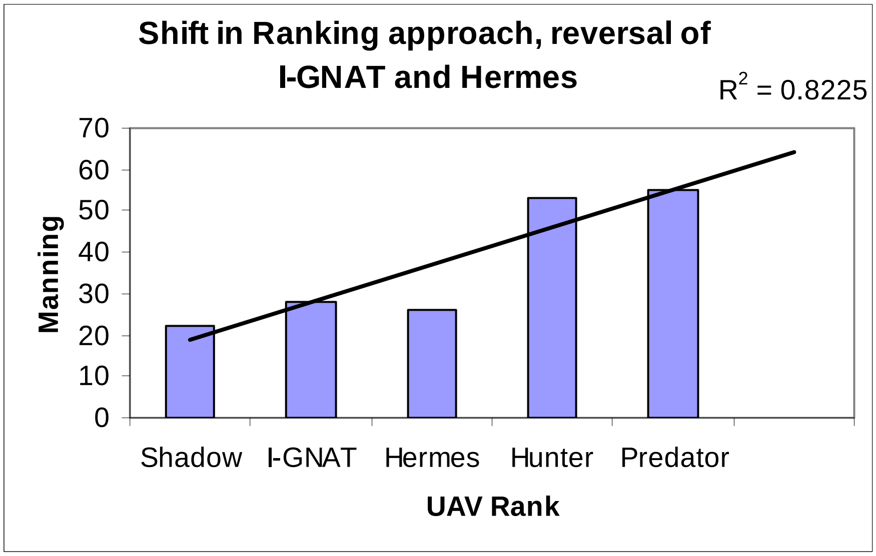


Figure F-6. Shift in ranking model, I-Gnat reversed with Hermes.

Summary of Leave-out Models and Shift-in-Rank Models

It is apparent that changes in the number of UASs used in the model or the rank ordering of the model have changes in the final fit and conclusions of the model; however, the level of change in either case is rather small. Shift in ranking appears to have the least effect, while the omission method does appear to change the conclusions. The leave-out method has its greatest effect when the most comparable UASs are omitted and its smallest effect when less comparable UASs are removed.

It is suggested that additional work could be performed to determine the degree of homoscedasticity of these models' fit. It might be expected that the influence of the "more similar UASs" model would affect the model's spread in each model's residuals. Plotting the residuals would also demonstrate the distribution of data across the model's range and provide another method for determining model fit other than just using R^2 (which reflects an overall effect). However, that level of statistical detail analysis should probably fall to an ensuing report.

Manning Regressions Using USAF Prototype UAS Manning Data (Predator B)

All of the previous models employed actual manning values for current UASs and then extrapolated one interval above the highest ranked system, and it is recognized that this is the highest risk approach to prediction. The next two approaches involve the inclusion of those same baseline data but with the addition of (a) predicted manning levels for a USAF proposed UAS (Predator B), and (b) actual manning values for a USAF UAS (Global Hawk) which is physically much larger and more technologically sophisticated than the current UASs studied so far. This approach is an example of interpolation using linear regression.

Figure F-7 shows the baseline UAS manning data with the inclusion of a next generation USAF (Predator B) manning estimate. Although this system has not flown yet, the manning value for the Predator B has been proposed (through a variety of means) to support this new UAS in deployed conditions. As such, figure F-7 mixes current and proven data with projected data for a future system (other than the one being predicted in this study!). The processes and rationale for the Predator B manning level are not known at this time, other than its manning value was derived to meet mission requirements not dissimilar to the proposed new Army UAS, that is, 24-hour operations with similar missions.

A review of figure F-7 indicates that a manning level of about 68.5 personnel would fit the "new Army UAS." This estimate is slightly higher than those derived with only actual current data, and it is an interpolation method that mixes demonstrated manning values with a projected value.

The next modeling approach is to look at the upper end extreme in UAS manning—that for the USAF Global Hawk UAS. This UAS is not only a very large technology and capability leap from that of the current UASs studied; it also represents a system that is physically several times larger than any of the systems studied (war-time manning levels of 117 personnel are required for the Global Hawk). In this regard, the inclusion of the Global Hawk will probably result in an

over-estimation of manning for the new Army UAS; however, it will also provide an upper limit to prediction, based on actual manning values for a deployed system. This model will also include the Predator B data (figure F-8).

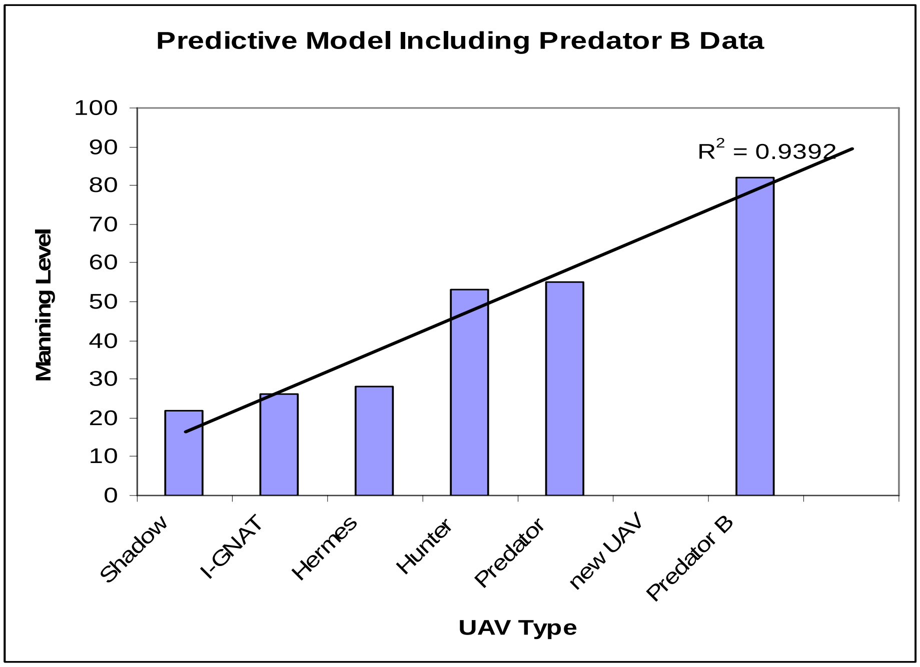


Figure F-7. Model including predator B manning data.

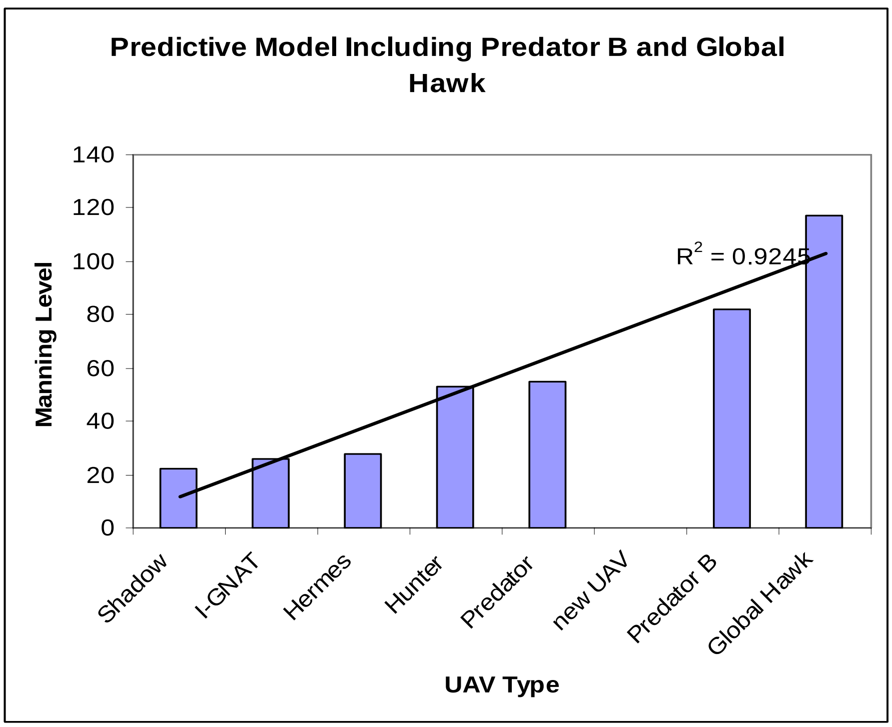


Figure F-8. Model including predator B and global hawk data.

This last model, which includes all the current UASs, the Predator B and the Global Hawk, should represent the upper limit of manning for the new UAS. Based on this model, an average of approximately 75 personnel for the new Army UAS is predicted, and this is the highest manpower estimate derived from this report. Because of the high number of personnel associated with the Global Hawk, the manning level for the new Army UAS created by this model appears to be inflated. Even if an exponential model were chosen to compensate for the outlier Global Hawk manning value, the prediction would still be at the level of 68.5 personnel for the new Army UAS.

Other Regression Modeling

The previous sections discussed in detail rank regression modeling using both extrapolation and interpolation approaches, and they explored some options for manipulating data in those models. They also explored various data sets or ranked combinations of variables. The following section demonstrates some manning projections based strictly on ratio scale data and common linear regression concepts.

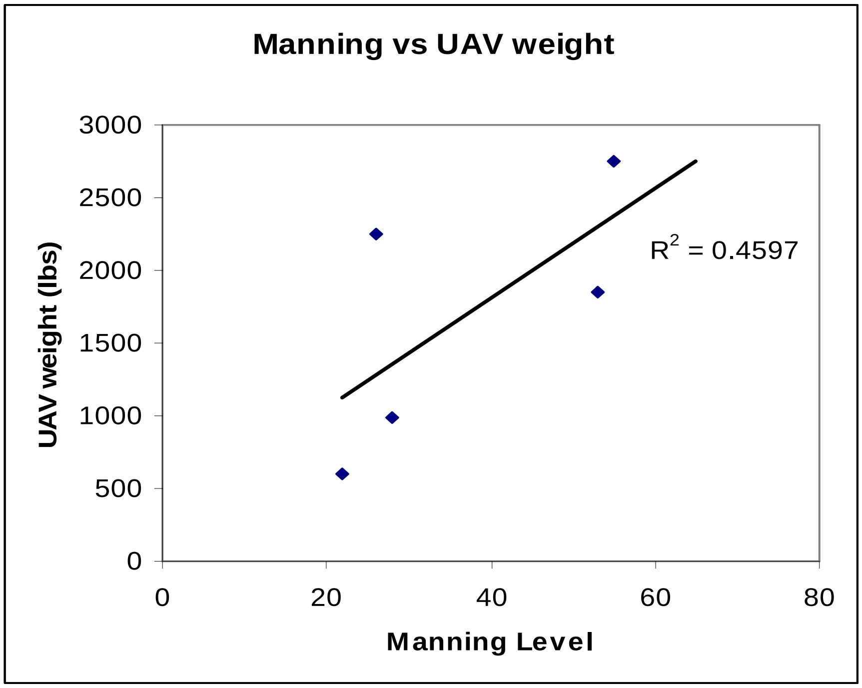
The first linear regression model compares manning levels to the gross weight of the aircraft. This approach has face validity from the fact that the larger the UAS is, the more personnel will be required to move it, maintain it, and operate it (currently, Army UASs are moved manually, as opposed to the use of tugs for large aircraft, and this is a critical variable that could influence Army UAS manning). (Note: If a tug or mechanized towing system were available for the proposed Army UAS, this could directly affect manning levels for those positions that involve physically moving the UAS.)

UAS Manning Versus Weight of the UAS

This manning estimate shows a more modest manning level and projects about 60 personnel for an aircraft of 2,750 lb (figure F-9).

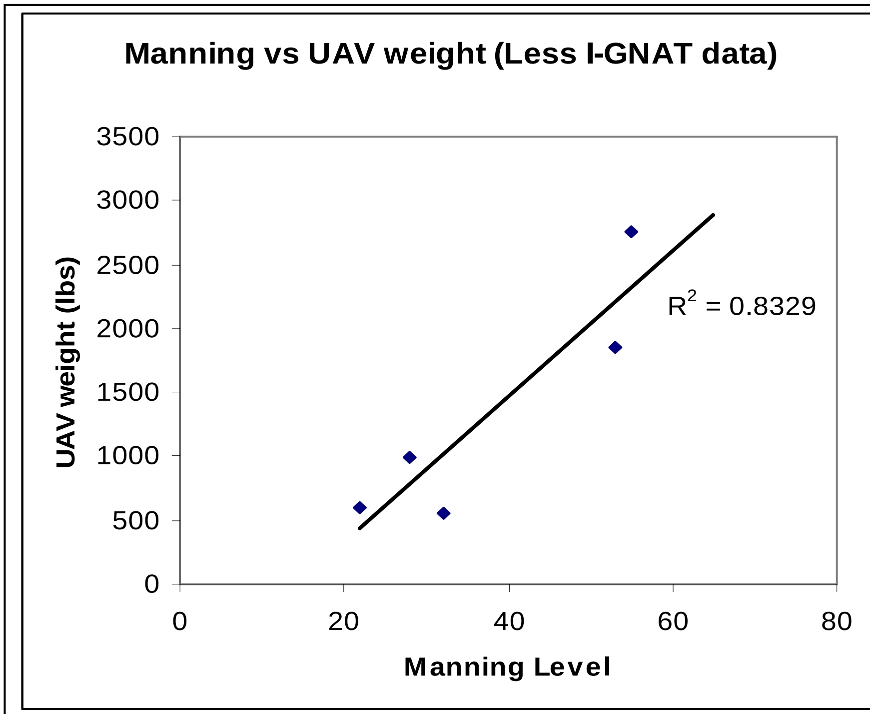
A review of figure F-9 shows a large deviation in the pattern associated with including the I-Gnat system (data point upper left of figure F-9). The I-Gnat is the most recent of all the UASs studied and was just introduced operationally in spring of 2004. If the data associated with I-Gnat were deleted and the current trend plotted again, a significantly different trend line and fit would result. Using the leave-out method, figure F-10 plots the current UAS data without the I-Gnat data.

Notice in figure F-10 that the model fit is considerably better (R^2 of 0.8329 versus 0.4597). When the I-Gnat data were not included, the model prediction of 68 personnel at 2,800 lb UAS weight is more in line with the manning values derived from the rank transform models. Again, it must be mentioned that the I-Gnat is very early in its deployment phase of operation, and manning operations and overall time in service have not been established as constants.



Note: Includes Shadow, Hermes, I-Gnat, Hunter, and Predator. This model predicts about 67 personnel and a weight of 2,750 lb for the new UAS. (If the new UAS weight is known, manning can be predicted.)

Figure F-9. Manning versus UAS weight.



Note: If weight is known, manning can be predicted.

Figure F-10. Manning versus UAS weight (removing I-Gnat data).

This is an example of how the insertion or deletion of select sample data can have a large effect on the model's outcome and internal model fit. Unlike the process of changing the order with rank order regression, the order is fixed in a ratio scale data model. In a ratio scale model, all data must follow their natural numeric order, and the only process that can be used is the leave-out method. It is also important to note that as a predictor, weight is very susceptible to advances in technology since one goal of aircraft design is always to reduce weight in order to gain flying performance (power-to-weight ratio enhancements).

UAS Manning as a Function of UAS First Flight Date

An interesting relationship can be plotted with the use of the first flight date of the same UASs versus the manning levels associated with them. This relationship is shown in figure F-11.

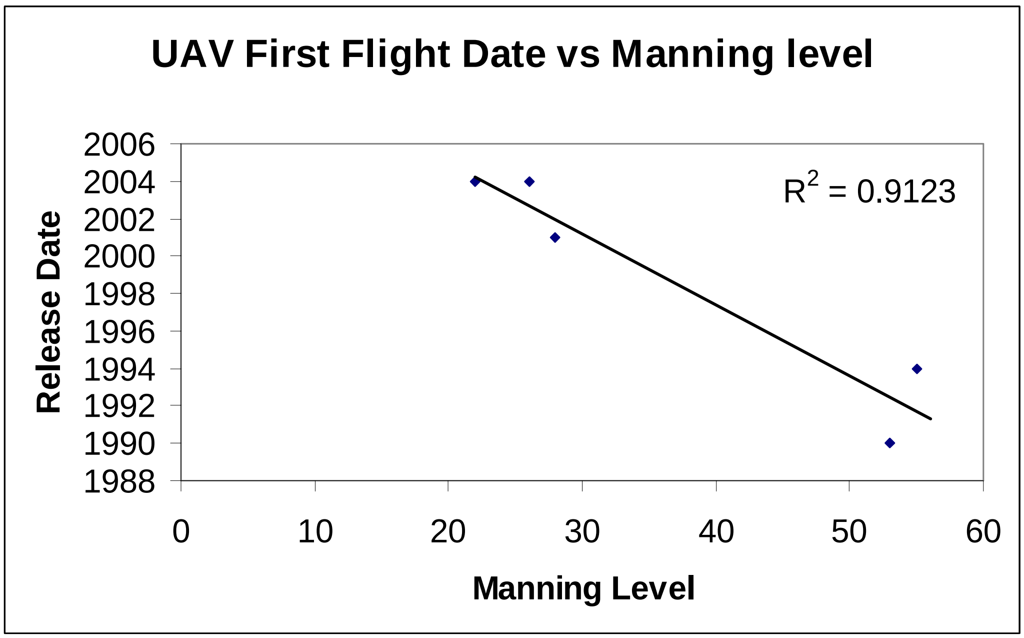


Figure F-11. UAS first flight date versus manning level.

Figure F-11 shows the relationship of manning to the variable of first flight chronology and includes the following UASs (proceeding from lower right to upper left of figure F-11): Hunter, 1990; Predator, 1994; Hermes, 2001; Shadow 2004, and I-Gnat, 2004.

The relationship of historical recency of production (by year) appears to be positively correlated (R^2 = .9123) to manning levels across all types of UASs, that is, newer UASs appear to require fewer personnel. However, in terms of prediction, figure F-11 must also be considered with caution since its logical trend would be toward zero personnel in less than 10 years, an interesting prediction considering the pace of automation, but probably not achievable in that time frame. However, there is reason to believe that this trend will continue because of system automation improvement over time and that UASs will reach a stage where technological innovation will reduce manning levels dramatically. However, it would be expected that this

trend shown in figure F-11 would also more likely reach a turning point or reach an asymptotic level in the near future in terms of manning (maintenance activities will for the foreseeable future still be focused on the human operator). Figure F-11 also illustrates the risk of prediction from limited data (only four systems considered), but it does make a point in regard to the trend in manning with newer systems, and that manning level estimates must consider many trends identified in the numerous models shown previously in this report. Information such as this (figure F-11) helped to moderate the conclusions from the models that followed before. This was one reason a linear model appeared to be better suited to prediction than an exponential model in that the rate of change seemed to match historical trends better than an exponential model. In addition, this last figure (F-12) could even lend some credence to a logarithmic model of decreasing manning values for new UASs.

An additional point of view in terms of historical trends in manning can be portrayed in figure F-12 where only large UASs are plotted. The size differential of UASs may also be a significant factor in the number of personnel needed for manning (as was seen in earlier regressions of UAS weight on manning levels).

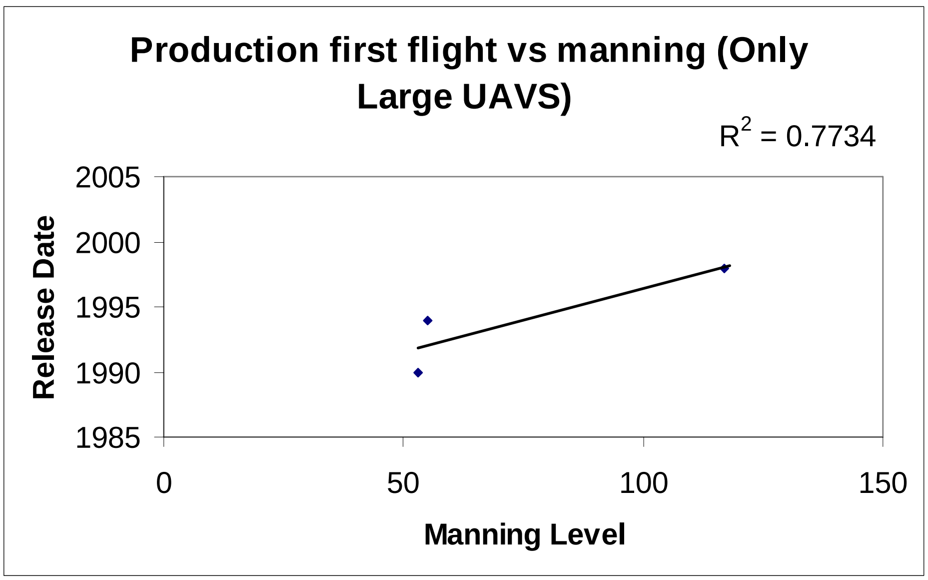


Figure F-12. Production first flight UAS manning (only large UASs).

Figure F-12 shows only Hunter, Predator, and Global Hawk, and yet there is still a strong positive relationship ($R^2 = .773$) shown to production first flight date versus manning (Hunter and Predator on lower left of figure F-12, Global Hawk on the upper right). If the I-Gnat were included, the relationship would change considerably with a very weak correlation R^2 of .22 (this figure is not shown). One conclusion is that the I-Gnat represents a considerable technological change that has affected manning; however, that conclusion should also be tempered by the fact that the I-Gnat system is very new and has a very small number of operating hours to its credit and has not established a firm manning level associated with its operations (unlike the UASs shown in figure F-12). These assumptions about possible cause and effect would best be settled

by another 8 to 9 years of operational data before a decision is rendered about manning levels based on one new system's manning level (the I-Gnat system), and the I-Gnat has not been operated to any great degree by military personnel. Another caution shown with this model is that the comparability of Global Hawk to all the other UASs shown is simply not valid for a variety of technical and operational reasons. This should be considered in the mathematical models for direct manning prediction. Essentially, the Global Hawk may represent a different level of system mission or complexity and thus is not comparable to the Army or USAF systems listed.

Statistical Discussion

Numerous reviews of the statistical procedures accomplished in this report were conducted. Notably, three primary reviews of overall method (not specific results) were conducted to determine if the general statistical theory and approaches used in this study were suitable. The author is indebted to the following distinguished professors of statistics for their review of parts of this document: Dr. William Jay Conover (University of Texas) Horn Distinguished Professor of Statistics; Dr. Dale O. Everson, Professor Emeritus of Statistics, University of Idaho, and Dr. Dallas Johnson, University of Iowa, Professor of Statistics (and statistical consultant to ARL). Considerable correspondence occurred between this author and these authorities regarding technical elements of the statistical approaches taken in this study.

Modeling Considerations, Modeling Validity, and Modeling Conclusions

In consideration of these modeling efforts, one important issue is the level of sophistication associated with the design of the new UAS, for example, the Global Hawk, which operates with a crew of four in the MCE (mission control element) (like a GCS) and with two in the LRE (launch recovery element) (similar to a small GCS). Even though it has a very large wing span and can navigate halfway around the globe without pilot intervention, the Global Hawk's reliance on automated systems for take-off, flight, and landing and most of its flight time reduces the reliance on the pilot as well as the air crew. With no need for daily or hourly maintenance (such as may be required by smaller current UASs), the Global Hawk operates with 61 (peace-time ops) to 117 (war-time ops) personnel and has an indefinite ops tempo with 40-hour missions. However, its basic maintenance crew is larger than current systems (44 peace-time, 94 war time for a 40-hour mission). In terms of the mathematical models, all the model versions tested in this report attained approximately the same values, between 66 and 68 personnel, with the outlier model that was based on the Global Hawk at a level of 75 personnel. This may be first-hand evidence of the effect of an outlier (Global Hawk) on a model, rather than indicating a valid trend toward much higher manning for a new system.

Manning Predictors Derived From Other Sources

The use of UAS data sources outside a particular study, in this case from another DoD research agency (AFRL), can provide an independent source of information that may be used to help predict results for a new but similar system. This analysis by similarity provides the opportunity to derive predictive values from similar systems that mirror the operational requirements of the proposed system.

Based on a manning study performed on Predator by the U.S. AFRL, an increase in USAF Predator manning to meet sustained 24-7 operations tempo was proposed as one of their recommendations. This recommendation suggested an approximately 24% increase in manning in order to meet extended period war-time surge 24-7 operations. Considering that Predator currently can complete a mission over a 24-hour period, the results of the AFRL study called into question how well operations were being performed at the current level of 55 personnel per Predator squadron per normal 24-hour mission. That is, operations are currently being accomplished with a crew of 55; however, as a result of the AFRL study, a strong recommendation was made that current manning levels for Predator were not adequate to effectively operate that system. This increase in the manning factor would increase manning to 65.72 persons per company if applied to the Hunter UAS with a current manning level of 53 persons (24% x 53 personnel = 65.72). If the same percentage increase were made for Predator, the result would be a Predator manning level of 68.2 personnel. Interestingly, several of this study's mathematical models mentioned earlier reached similar manning conclusions regarding 24-hour operations for the proposed new UAS, using completely orthogonal approaches.

Field Personnel Comments on Manning

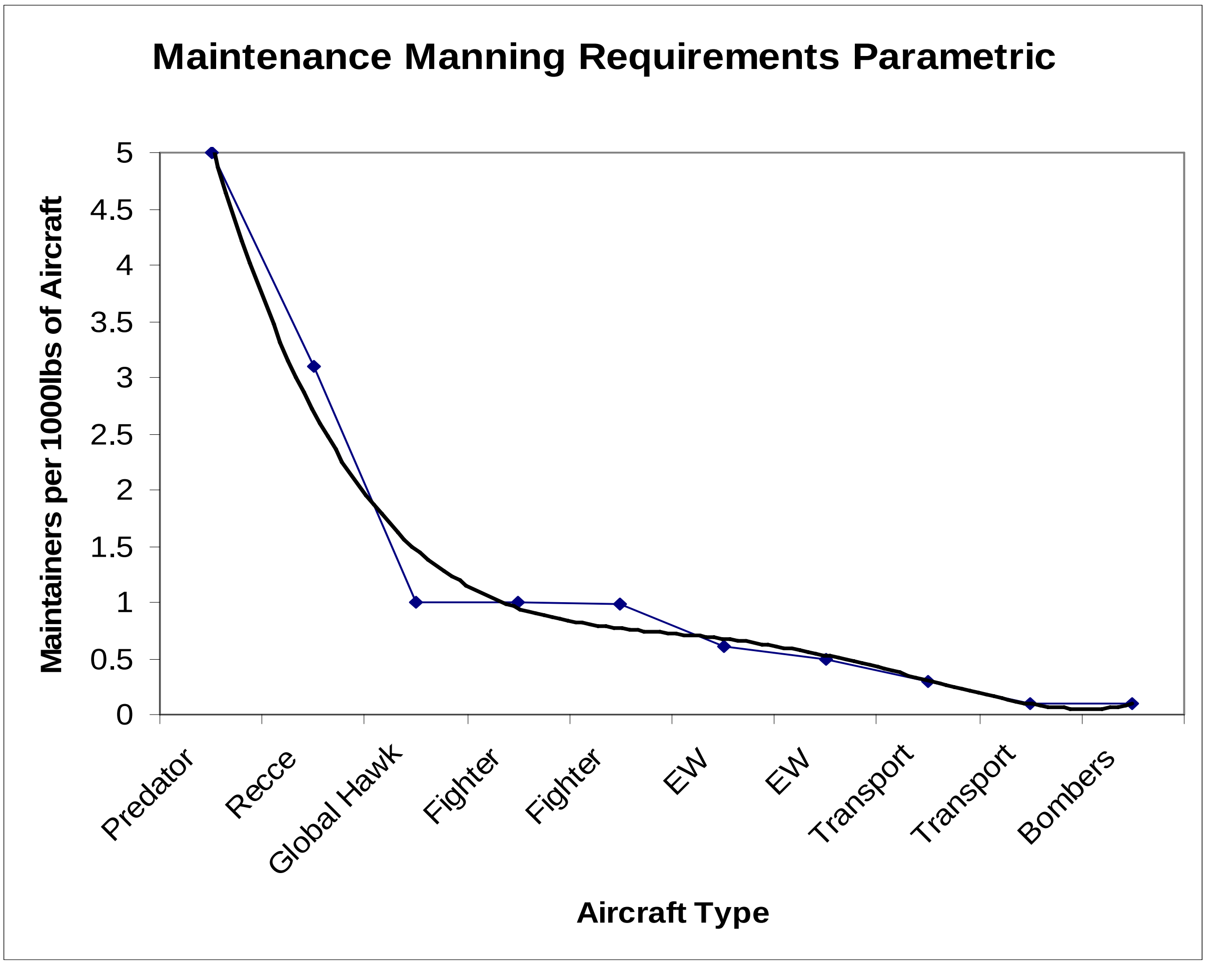
A critical factor mentioned by field personnel is accounting for the AVO and MPO positions. During a recent manning study interview, comments from a senior Shadow NCO MC indicated that AVO and MPO manning for the Shadow should be increased by a factor of two to three times to meet surge needs. Likewise, a senior instructor at the Army training school recommended to the author a minimum manning level of 28 personnel per Shadow company as a more suitable (than the standard 22 personnel) manning level. An alternate point of view would be to apply the AFRL recommendations as a percentage across the board to Army UASs to see the manning implications. This would result in manning levels of 28 for Shadow, 32 for I-Gnat, and 66 for Hunter. Compare this value to the mathematical model manning estimates for the new UAS, and there is a close concurrence of new system UAS manning to the AFRL increase percentage value of 66 personnel for the Hunter.

Maintenance Manning

To discuss the implications of maintenance manning by aircraft type, see figure F-13. This figure is based on work completed by the Lockheed Martin Corporation from 1999-2004,

entitled *Design of UAV Systems, Reliability, Maintainability, Supportability, and Safety* and was provided by Dr. Armand Chaput from the University of Texas.

Figure F-13 shows that as weight and size increase, the manning requirement for maintenance decreases across aircraft platforms. That is, the number of maintainers per thousand pounds of aircraft decreases with increasing aircraft weight. This may be an important factor to consider when one is planning manning estimates for large UASs that are currently *much smaller and lighter* aircraft than the vast majority of military aircraft.



Note: Manpower parametric based on aircraft max speed (kts), and weight (speed and weight values *not shown* to enhance figure simplicity).
Note: Maintainer value is derived from the expression: maintainers/[EW+Wpay]/(#/Klb) in which EW = empty weight and W pay = payload weight (retained or expendable payload), and #Klb = AV weight in thousands of pounds.

Figure F-13. Maintenance manning requirements parametric.

There are a number of reasons for the phenomenon of decreasing maintenance manning with increased size and performance aircraft. One of the most significant reasons is that overall system reliability is not nearly as high for physically smaller aircraft systems. Another factor is that engine/airframe maintenance of large aircraft is an order of magnitude less than for small systems; for example, Predator requires a maintenance inspection of the engine at 50 hours and

has a maintenance crew of 18 to 24 to support 24-hour operations. A typical turbine engine military aircraft can go several hundreds of hours before a detailed engine inspection. In addition, the more sophisticated the aircraft, the greater the degree to which it can be maintained via electronic means; for example, the F/A-22 is currently being maintained in a flight test status with a 12-hour shift crew of five to six personnel (two technicians, one to two mechanics, one quality assurance inspector, and one crew chief (Proteau, F/A-22 CTF Edwards Air Force Base, personal communication, February 2005). It is also notable that larger and more sophisticated aircraft have electronic troubleshooting systems that allow a complete diagnostic to be performed without anyone lifting a screwdriver. Considering that the F/A-22 has a take-off weight of between 40,000 and 60,000 pounds and is capable of supersonic flight, it serves as an example that the larger, faster, heavier, and far more sophisticated aircraft actually requires fewer maintenance personnel proportionately than smaller, slower, and considerably lighter UASs.

A final factor considered in the modeling was a comparison of accident rates over time for two dissimilar systems, Pioneer and Hunter. These represent a small UAS and a large UAS. The data are interesting because even with comparable hours, the accident frequency is order of magnitude higher for the smaller Pioneer versus Hunter, while the overall pattern over time is very similar: figures F-14 and F-15 show accident (excluding combat losses). Note: Each point graphed indicates a 1-year period. With Hunter, one anomalous outlier year (1995) was deleted to preserve the integrity of the model's trend line; that rate was 0.01. Hunter years were 1991 to 2005; Pioneer years were 1986 to 1995.

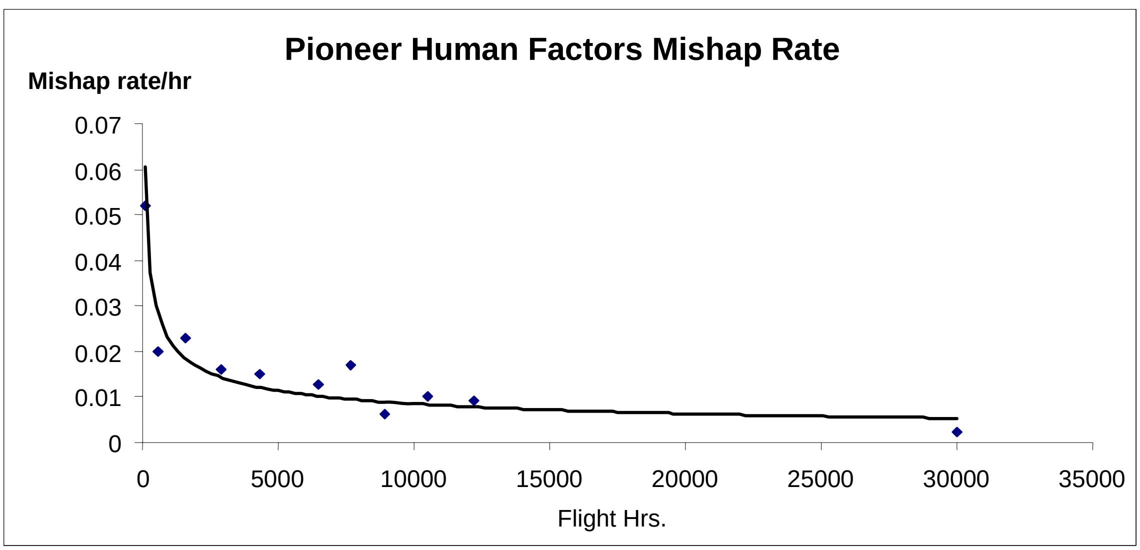


Figure F-14. Pioneer human factors mishap rate.

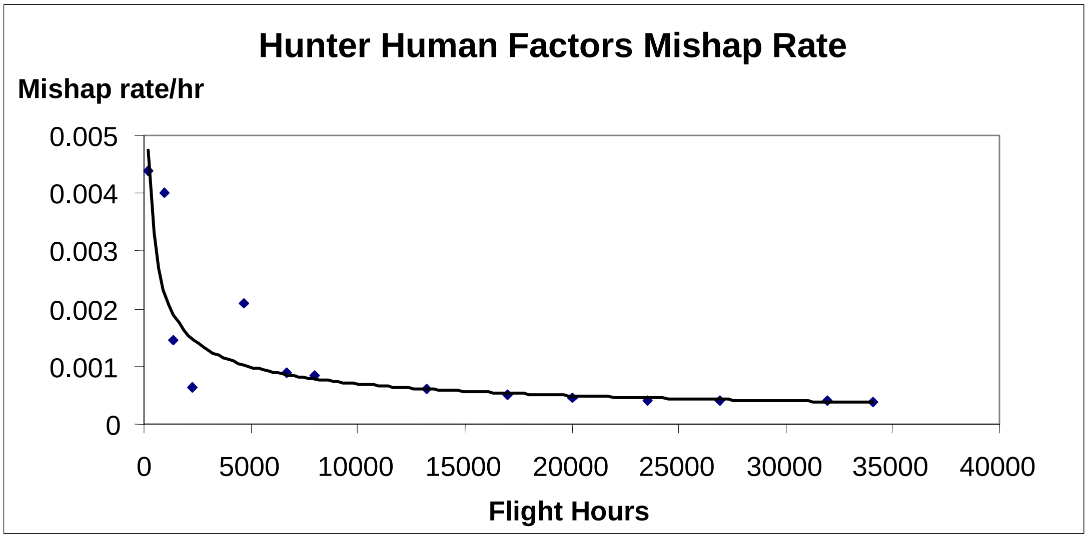


Figure F-15. Hunter human factors mishap rate.

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Appendix G. Spiral Development and Manning

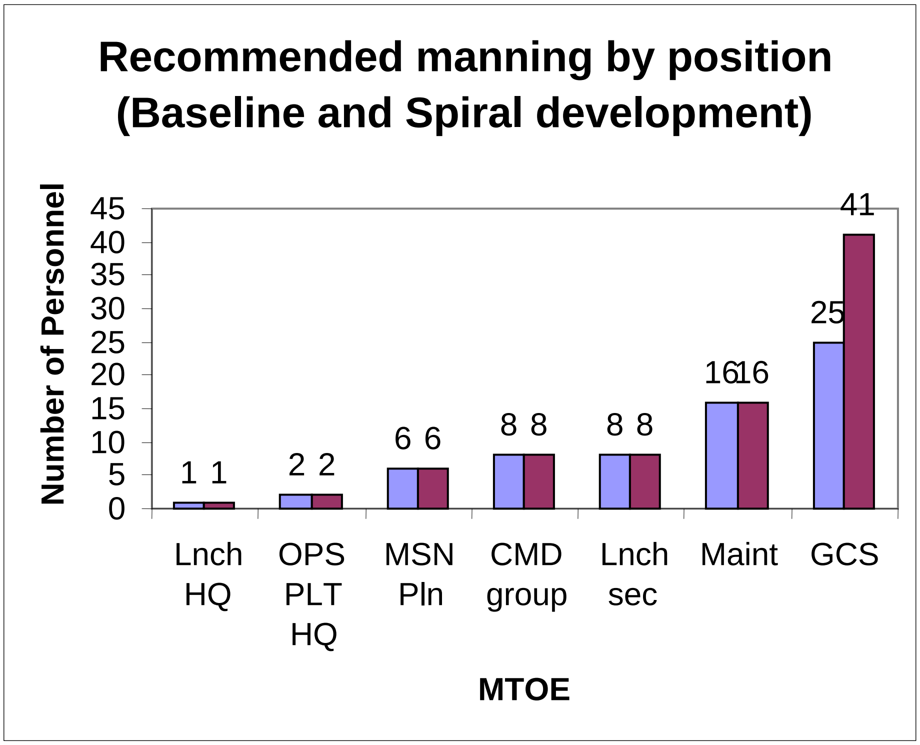

Figure G-1. Baseline and spiral development manning breakdown (left [blue] bars are baseline and right [red] bars are spiral development).

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Appendix H. MTOE and Manning

Table H-1 and figure H-1 illustrate organizational and spiral development manning levels. (Note: Charts were taken from ER/MP manning study report.)

Table H-1. Manning breakdown by position.

MTOE Recommendation Chart	Duty Title	Baseline Manning	Growth or Spiral Development Manning Level
Command Group	Company Commander	1	1
	First Sergeant	1	1
	Executive Officer	1	1
	Supply Sergeant	1	1
	Communication	2	2
	Armorer	1	1
	NBC NCO	1	1
Operations Platoon HQ	Platoon Leader	1	1
	Platoon Sergeant	1	1
Mission Planning	Sergeant	3	3
	AVO/MPO	1	1
	OPS Tech	1	1
	Aviation OPS	1	1
Ground Control Section	UAS MC	1	1
	UAS AVO/MPO	20	32
	PGCS	4	8
Launch Recovery HQ	Platoon Leader	1	1
Launch Recovery Section	UAS Sergeant	2	2
	MC	2	2
	Weapons/Ordnance	4	4
Support Section Contractors	Maintenance Officer	1	1
	IEW systems repair	8	8
	Power general mechanic	4	4
	Petrol vehicle operator	2	2
	The Army Maintenance Management System-UAS	1	1
Contractor Support Total		16	16
Total Personnel		66	82

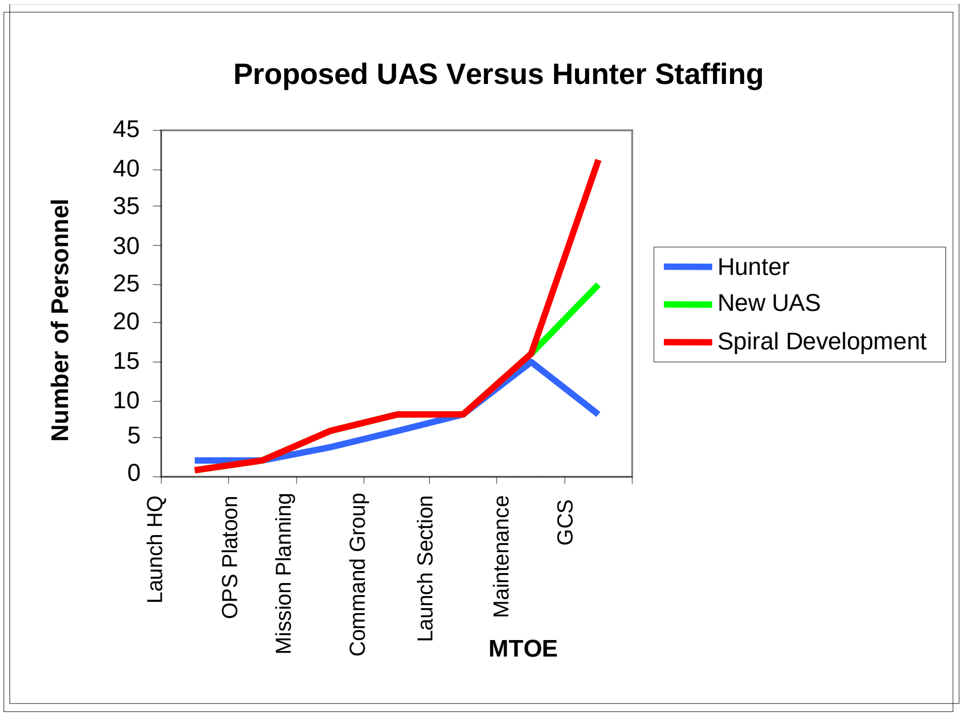

Figure H-1. New UAS (ER/MP) versus hunter staffing.

Appendix I. Additional Sample Recommendations for a Typical New UAS (ER/MP)

1. Army UAS commanders, lieutenants, and warrant officers should attend an abbreviated course on UAS fundamentals for this new UAS.

This is a lesson learned from the USAF, where rated pilots fly their UASs, and it is strongly encouraged by study of USAF UAS operations and recommendations from Army field and training personnel that this additional level of knowledge by the UAS command staff would improve Army UAS safety and operational effectiveness.

2. Increased capability of the new UAS will require additional training time allocation in the formal UAS training school system.

Formal crew training will probably need to be increased by several weeks to accommodate the greater capability of the new UAS, particularly areas involving Class V munitions, SIGINT, ASTAMIDS, LIDAR, hyper spectral, METS SMS, WCP, NBC, and other ER/MP growth options. Recommend consultation with TRADOC and Army UAS school representatives to develop appropriate time frames.

3. An on-duty, flight time, work period of 3.0 hours or less should be adopted by Army AVO and MPO UAS personnel for the new UAS OPS.

Human performance in cognitive tasking such as seen in AVO and MPO operations begins to degrade in as little as 30 minutes, with research indicating that targets can be missed at rates exceeding 30% after 1 hour's operation. In addition, fatigue and the infrequent nature of target detection (en route) contribute to diminished effectiveness; consequently, shorter periods on station can provide enhanced human performance for these particular tasks.

4. The total flying duty day should be reduced to a 6-hour flight shift for AVOs and MPOs for the new UAS. Total duty day should ensure crew rest minima, regardless of extra duties assigned.

Reduced time on station often equates to more effective detection of targets, fewer errors made, and greater effectiveness for tasks that are not as physically challenging as actual aircraft flight. Static body positioning in a GCS may result in attention deficits that exceed those in manned aircraft operation; thus, fewer hours should be spent working these tasks than in manned aircraft flight. Additional duties have been reported by Army and Air Force personnel to infringe on crew rest minima.

5. Within the shift recommendations listed, a plan should be fielded to adjust the number of personnel available for take-offs and landings to balance workload levels for the new UAS.

Workload for all members of the ground control group is highest at take-off and landing; thus, manning should be temporarily increased at that time to allow better distribution of workload and then reduced during the middle part of the mission segment (personnel transferred to other UAS duties during that time are better used).

6. It is recommended that the new UAS could accrue a manpower reduction as a result of the control of multiple UASs from a single GCS. This issue should be studied in detail.

Other DoD agencies are actively pursuing the idea that multiple UASs can be commanded from a single GCS. It is believed that a technological solution can be achieved with developmental Army UASs such as this new UAS that will allow this goal to be achieved, and this effort should be supported by research.

7. It is recommended that maintenance manpower reduction initiatives be investigated for this new UAS.

Currently, UASs have higher maintenance manpower requirements than any conventional, manned aircraft. It is believed that this could be changed through investigation of maintenance factors for UASs that drive those higher levels of maintenance manpower.

Acronyms

AFRL	Air Force Research Lab
AFSC	Air Force Service Codes
AGE	air ground equipment
AGL	Above Ground Level
AGCS	advanced ground control station
ARL	U.S. Army Research Laboratory
ASTAMIDS	airborne standoff minefield detection system
AV	Air Vehicle
AVO	air vehicle operator
BDA	battle damage assessment
BN	battalion
C2	command and control
C4I IP	command, control, communications, computers, and intelligence
DEMPC	data exploitation manager personal computer
DETCO	detachment commander
DoD	Department of Defense
EPE	electrical power equipment
ER/MP	extended range/multipurpose (UAS)
FOD	foreign object damage
GCS	ground control station
GDT	ground data terminal
GPS	global positioning system
HQ	headquarters
IEW	intelligence and electronic warfare
IMPRINT	Improved Performance Research Integration
JUCAS	Joint Unmanned Combat Aircraft System
LIDAR	light detection and ranging
MC	Mission Commander
MET	meteorological
MI	military intelligence
MOPP	mission-oriented protective posture
MOS	military occupational specialty
MPO	mission payload operator
MTOE	modification table of organization and equipment
Mx	maintenance
NBC	nuclear, biological, and chemical
NCO	non-commissioned officer
OPS	operations
ORD	operational requirements document
OSD	Office of the Secretary of Defense
PGCS	portable ground control station
PGDT	portable ground data terminal
RSTA	reconnaissance, surveillance, and target acquisition
RVT	remote video terminal

SAR	synthetic aperture radar
SATCOM	satellite communication
SIGINT	signal intelligence
SME	subject matter expert
SMS	surety material sampling
SNCO	senior non-commissioned officer
TALS	tactical automatic landing system
TC	training circular
TOC	tactical operations center
TRADOC	Training and Doctrine Command
TRD	tactical requirements document
TSM	TRADOC System Manager
UAS	unmanned aerial vehicle
USAF	U.S. Air Force
VERSA	a VME type
VME	VERSA module Euro card bus (a 32-bit bus)
WCP	warfighter communications payload
WIN-T	warfighter information network-tactical

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